# novative Approaches Understanding ansportation/Societal nteractions

REPORT NO.
UMTA-MA-06-0039-81-1
DOT-TSC-UMTA-81-61,1

TSC Urban and
Regional Research Series

Volume 1-
Program Overview and
Executive Summaries

Final Report
October 1981

UMTA Office of Planning
Methods and Support

U.S. Department of Transportation
**Urban Mass Transportation Administration**
Office of Planning
Management and Demonstrations
Washington D.C. 20590



## NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

## NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Technical Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| UMTA-MA-06-0039-81-1 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| INNOVATIVE APPROACHES TO UNDERSTANDING TRANSPORTATION/ SOCIETAL INTERACTIONS<br><br>VOLUME 1 - PROGRAM OVERVIEW AND EXECUTIVE SUMMARIES | October 1981 |
| | 6. Performing Organization Code: DTS-24 |
| 7. Author(s) | 8. Performing Organization Report No.: DOT-TSC-UMTA-81-61,I |
| 9. Performing Organization Name and Address<br>U.S. Department of Transportation*<br>Research and Special Programs Administration<br>Transportation Systems Center<br>Cambridge MA 02142 | 10. Work Unit No. (TRAIS): UM-117/R-2646<br>11. Contract or Grant No.: DTRS-57-80-C-00032 thru 38 |
| 12. Sponsoring Agency Name and Address<br>U.S. Department of Transportation<br>Urban Mass Transportation Administration<br>Office of Planning Management and Demonstrations<br>Washington, DC 20590 | 13. Type of Report and Period Covered<br>Final Report<br>(June 1979 - June 1980)<br>14. Sponsoring Agency Code: UPM-20 |



15. Supplementary Notes *Supporting Contractors and Contract Sequence Numbers:
Cambridge Systematics, Inc. (00032)
DAA Enterprises, Inc. (00033)
Futures Group (00034)
Interchange (00035 and 00036)
Research Triangle Institute (00037)
University of Chicago (00038)

16. Abstract

This report documents seven innovative approaches for analyzing relationships between transportation and spatial, social, and economic structures in the United States. The approaches were developed by six contractors as part of an UMTA/TSC research program. The report is divided into two volumes:

Volume 1 - Program Overview and Executive Summaries (88 pages) contains a description of the research program and executive summaries of the seven analytic approaches as documented in Study Design Reports prepared by the contractors.

Volume 2 - Study Design Reports (786 pages) contains the seven Study Design Reports which describe in detail the proposed analytic approaches.

The seven approaches and corresponding contractors are listed below:

| | |
|---|---|
| Cambridge Systematics | - Residential Housing and Location Model |
| DAA Enterprises | - Systems Dynamics Model |
| Futures Group | - Probabilistic Systems Dynamics Model |
| Interchange | - Analysis of Demography, Housing and Transportation |
| Interchange | - Micro-Economic Model |
| Research Triangle Institute | - Comparative Analysis of Urban Spatial Structures |
| University of Illinois | - Societal Linkages Model |


| 17. Key Words | 18. Distribution Statement |
|---|---|
| transportation, spatial analysis, economics, social systems, systems dynamics, simulation, demographics, location, modeling | DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 88 | |

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Technical Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| UMTA-MA-06-0039-81-1 | PB82-159021 | |

| 4. Title and Subtitle | |
|---|---|
| Innovative Approaches to Understanding Transportation/Societal Interactions. Volume 1 - Program Overview and Executive Summaries. | 5. Report Date: October 1981 |
| | 6. Performing Organization Code: DTS-24 |
| 7. Author(s) | 8. Performing Organization Report No.: DOT-TSC-UMTA-81-61,I |
| 9. Performing Organization Name and Address: U.S. Department of Transportation, Research and Special Programs Administration, Transportation Systems Center, Cambridge, Massachusetts 02142 | 10. Work Unit No. (TRAIS): MA-06-0039(UM-117/R-2646) |
| | 11. Contract or Grant No.: DTRS-57-80-C-00032 thru 38 |
| 12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Urban Mass Transportation Administration, 400 Seventh Street, S.W., Washington, D. C. 20590 | 13. Type of Report and Period Covered: Final Report, June 1979 - June 1980 |
| | 14. Sponsoring Agency Code: UPM-20 |

15. Supplementary Notes

Volume 2 of this report is: "Study Design Reports" (UMTA-MA-06-0039-81-2).

16. Abstract

In 1979, the Transportation Systems Center (TSC), under sponsorship of the Urban Mass Transportation Administration (UMTA), began a program of research directed toward improving the understanding of the role of transportation in society, in particular with respect to patterns of travel, location, and development. As a major element of the program, innovative approaches to defining, structuring, or solving the problems were sought from the research community. This report contains seven study design reports prepared by six research firms who were awarded contracts to produce detailed work plans for refining and demonstrating proposed innovative analytic approaches to understanding transportation/societal interactions. The seven approaches and corresponding contractors are: 1) Cambridge Systematics - Residential Housing and Location Model; 2) DAA Enterprises - Systems Dynamics Model; 3) Futures Group - Probabilistic Systems Dynamics Model; 4) Interchange - Analysis of Demography, Housing, and Transportation; 5) Interchange - Micro-Economic Model; 6) Research Triangle Institute - Comparative Analysis of Urban Spatial Structures; and 7) University of Illinois - Societal Linkages Model.

This report is divided into two volumes. This volume, Volume 1, contains the Executive Summaries of the study design reports, a description of the research program, and technical evaluations of the seven study designs by a TSC/UMTA review team. Volume 2 contains the study design reports.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Demographics; Economic Structures; Economics; Models and Modeling; Simulation; Social Systems; Socioeconomics; Spatial Analysis; Systems Dynamics; United States | Available to the public through the National Technical Information Service Springfield, Virginia 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 88 | A05 |

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

## PREFACE

In 1979 the Transportation Systems Center (TSC), under sponsorship of the Urban Mass Transportation Administration (UMTA), began a program of research directed toward improving the understanding of the role of transportation in society, in particular with respect to patterns of travel, location and development. As a major element of the program, innovative approaches to defining, structuring or solving the problem were sought from the research community.

This report contains seven study design reports prepared by six research firms who were awarded contracts to produce detailed work plans for refining and demonstrating proposed innovative analytic approaches to understanding transportation/societal interactions. The research efforts described include development of: a residential housing and location model, a methodology for comparative analysis of urban spatial structures, two systems dynamics models, a micro-economic model, a societal linkages model and an analysis of demography, housing and transportation.

The report is divided into two volumes: Volume 1 contains the executive summaries of the study design reports, a description of the research program, and technical evaluations of the seven study designs by a TSC/UMTA review team; Volume 2 contains the study design reports.

This report was prepared by TSC's Urban and Regional Research Division under project funding from UMTA's Office of Planning Methods and Support. The work reported here was completed under the direction of Donald Ward of TSC. Project specification and overall program guidance were provided by Lee Jones of UMTA. Final preparation of this report was the responsibility of Michael Couture of TSC. The six contractors who prepared the study design reports and executive summaries contained herein were:

Cambridge Systematics, Inc.
238 Main Street
Cambridge, MA 02142

Research Triangle Institute
P.O. Box 12194
Research Triangle Park, NC 27709

Interchange
1844 Massachusetts Avenue
Lexington, MA 02173

DAA Enterprises, Inc.
675 Massachusetts Avenue
Cambridge, MA 02139

Futures Group
76 Eastern Boulevard
Glastonbury, CT 06033

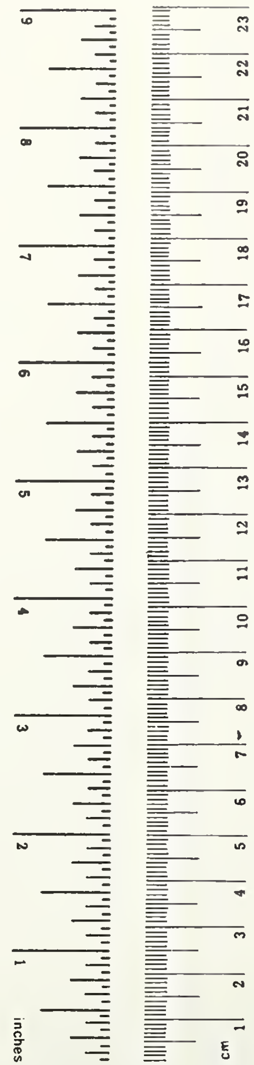
University of Illinois at Chicago Circle
Urban Systems Laboratory
Box 4348
Chicago, IL 60680

# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

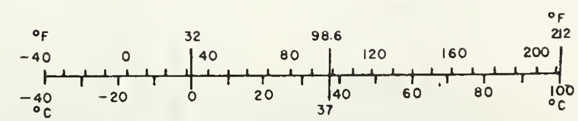
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inchas | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | milas | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimetera | $cm^2$ |
| $ft^2$ | square faet | 0.09 | square metara | $m^2$ |
| $yd^2$ | square yards | 0.8 | square metera | $m^2$ |
| $mi^2$ | square milas | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnea | t |
| | | **VOLUME** | | |
| tsp | teespoons | 5 | milliliters | ml |
| Tbsp | teblespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | querts | 0.95 | liters | l |
| gel | gellons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fehrenheit tempereture | 5/9 (after subtrecting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286. Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.




## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | squere centimeters | 0.16 | squere inches | $in^2$ |
| $m^2$ | square meters | 1.2 | squara yards | $yd^2$ |
| $km^2$ | squara kilometers | 0.4 | squara milas | $mi^2$ |
| he | hectaras (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



# CONTENTS

## VOLUME 1 - Program Overview and Executive Summaries



## VOLUME 2 - Study Design Reports

Under separate cover.

# 1. BACKGROUND

The Urban and Regional Research Division of the Transportation Systems Center (TSC), under sponsorship by the Urban Mass Transportation Administration (UMTA), has been conducting a program of research aimed at improving the understanding of transportation as it relates to spatial, social and economic structures in the United States. As part of this program, innovative approaches to analyzing the complex interactions between transportation and society were sought.

In June 1979, a Request for Proposal (RFP) was issued by TSC to some two hundred prospective contractors for developing such innovative analytic approaches. The major product called for in the RFP's Statement of Work was a "Study Design Report" which was to document in detail the contractor's proposed approach. The contract deliverables also included a Master Program Schedule and Business/Cost Proposal for carrying out the research proposed in the Study Design Report.

The contract process was divided into two phases: (1) contract awards were made to multiple contractors for development of Study Design Reports and (2) subsequent to an evaluation of the delivered Study Design Reports by TSC and UMTA, awards were made (through contract modifications) to several contractors to implement the approaches described in their Study Design Reports.

Twenty-eight proposals were received in July 1979 in response to the RFP. Seven awards were made to six contractors for producing Study Design Reports. The six contractors receiving awards were:

Cambridge Systematics, Inc.
Development Analysis Associates, Inc.[1]
Futures Group
Interchange (1) and (2)[2]
Research Triangle Institute
Urban Systems Laboratory (University of Illinois at Chicago Circle)

Each contractor was given from eight to ten weeks from the contract execution date to complete the Study Design Report. In May 1980 technical presentations of the completed Study Design Reports were made by the contractors to the TSC/UMTA evaluation team. Upon review of the seven Study Design Reports and technical presentations, the evaluation team recommended follow-on funding for implementation of approaches proposed by two contractors: Research Triangle Institute and Interchange (1).

The approaches proposed by RTI and Interchange were considered particularly innovative and the corresponding study designs were sound. RTI proposed to integrate concepts from information theory, urban trip distribution modeling and multidimensional scaling to analyze and quantify structural associations between urban population, employment, activity, land use and transportation network patterns. This work was seen as having the potential for providing a new, valuable framework for urban policy analysis, planning and research. Interchange (1) proposed a research effort which would document

[1] Name changed later to DAA Enterprises, Inc.

[2] Interchange was awarded contracts for two different Study Design Reports.

and analyze forthcoming demographic changes, their implications for metropolitan residential patterns and growth policy, and in turn their implications for transportation policy. This kind of analysis could be used directly by transportation planners and officials to provide a clearer understanding of the demographic, housing and growth policy context in which the transportation investment decisions of the 1980's will be made.

## 2. ORGANIZATION OF THE REPORT

The primary intent of this report is to disseminate information on the analytic approaches developed in the seven Study Design Reports prepared in Phase 1.

The report is divided into two volumes. This first volume describes briefly the research program and summarizes the Study Design Reports. It contains the contract Statement of Work (Section 3), executive summaries of the Study Design Reports (Section 4) and review comments of the UMTA/TSC evaluation team (Section 5). The second volume contains the seven Study Design Reports.

The Study Design Reports and executive summaries are included as submitted by the contractors. Only minor editing has been performed. Sections of the Study Design Reports pertaining to project management and resource requirements have been deleted, except for project schedules. The deleted sections are indicated in each report's table of contents in Volume 2 by asterisks (*).

# 3. STATEMENT OF WORK

## A. Background

It is recognized that improvements in transportation broaden the range of alternatives available to decision-makers in our society - alternatives related to travel, location, and development. The very rapid increases in accessibility seen through the 1950's and 1960's (interstate highway system, urban freeways, jet travel) produced major changes in lifestyles and ways of doing business. Now, the expansion of options is slowing and, in some cases, reversing as factors related to energy cost and availability, environmental concerns, and funding limitations significantly affect individual lifestyle choices and institutional investment opportunities. Many of these constraints apply strongly to transportation and will greatly influence the implementation of future major transportation projects. Each project will have to show benefits greater than costs in a decision-making arena where social and environmental costs may be weighed more heavily and pure accessibility benefits more lightly than has been the case historically. Further, the cost of transportation improvements may be rising so quickly that expenditures heretofore "allocated" to transportation may be seriously considered for other sectors of society.

In general, major transportation projects will be sought that will lead to development patterns deemed desirable. Of course, what constitutes "desirable" development patterns remains an open and difficult question. It is likely to be answered only indirectly and implicitly as policy-and decision-makers select alternatives that they hope are consistent with broad societal goals and objectives. However, until the role that transportation plays in society is better understood, decisions will continue to be made under great uncertainty, and the results of those decisions questioned.

One call for more work to be done in this general area was described in the proceedings of the Conference of Transportation and Land Development (Transportation Research Board Special

Report 183). As part of the proposed action agenda, research needed in the area of transportation and national urban policy was discussed:

> "1. The formulation and application of policy dealing with the future patterns of cities and development could be analyzed. An examination of intelligent cooperation with the inevitable versus meeting the future with purpose should occur.
>
> 2. The application of transportation as an expression of and an element in national policy should be identified. Then an evaluation of that experience and clarification of the role of transportation in achieving national objectives could take place.
>
> 3. The interactions of economics, energy, land use, housing, water and sewer facilities, for example, should be examined as they relate to national urban policy but with particular reference to transportation. This might lead to a better understanding of transportation's strategic place in national policy definition and application."

The general aim of this program is to improve our understanding of how transportation influences long-term spatial patterns through complex interactions of social and economic forces. In spite of a large number of theories, models, and model systems developed to examine the relationship, or particular aspects of the relationship, of transportation and spatial form, knowledge in this area, especially of the kind that can be usefully applied to policy or planning considerations, is extremely limited. Theoretical approaches, including much early work in the field, have been characterized by idealized basic assumptions and simplistic modelling of the transportation and economic systems. While they are useful in establishing and examining a few fundamental relationships that provide a basis for more comprehensive approaches, the methods by themselves have often produced results that tend to exaggerate the importance of transportation effects due to the omission of important factors.

Empirical methods utilizing aggregated data have been widely used to forecast "land use" in the traditional urban transportation planning process. The models, although widely used, have often been labelled "descriptive" because their designs contain no causal or behavioral mechanisms. For this reason, their use in assessing long term structural changes in society is limited.

Other approaches that are largely experimental include those based on disaggregate behavioral modelling, which has had some success in the area of travel demand; those making use of intuitive or deductive relationships, such as the urban dynamics methodology; and those based on representing social and economic processes by the physical sciences.

## B. Objective

The Urban and Regional Research Division of the Transportation Systems Center, under sponsorship of the Urban Mass Transportation Administration, wishes to develop a program of research to improve the understanding of the role of transportation in society, in particular with respect to patterns of travel, location, and development. This research should help to improve the capability of answering such questions as:

1. What would be the effects of major, significant long-term improvements in transportation in this country? In intercity transportation? In urban areas? In freight transportation?

2. What kinds of long-term actions and policies related to development and investment in other than the transportation sector can be combined with transportation improvements to produce synergistic benefits?

3. What would be the effects of <u>no</u> major transportation improvements implemented in the foreseeable future? What is the real value of mobility in our society?

4. How does transportation influence the comparative advantage of cities or regions with respect to other cities? With respect to non-urban areas? With respect to particular types of activities?

Innovative approaches are sought - approaches that represent new ways of defining, structuring, or solving the problem.

It is likely that a number of studies will be supported under this program. While it is intended that few constraints be placed on responses to this broad subject area, a number of criteria may be used to judge the potential of proposed ideas, such as the following (these should be considered as guidelines, and not binding constraints):

1. Approaches should be potentially generalizable rather than narrowly focussed or localized.

2. Approaches should be useful for assessing primarily long-term effects.

3. Approaches should have some longitudinal, or dynamic, content rather than be solely cross-sectionally structured.

4. Approaches should be based on some theoretical development rather than purely empirical correlations.

5. Approaches should not be designed such that (ultimately) testing, validation, or exercising with real-world data are not theoretically possible, i.e., purely academic approaches are discouraged.

6. Approaches should be concerned with development of new, improved, or extended concepts, and efficient ways of testing those concepts, rather than with routine or large scale model building.

C. Detailed Statement of Work

The contractor shall furnish the necessary personnel, facilities, services, materials and equipment to accomplish the work set forth herein.

Item 1 - Study Design Report - Develop an approach to analyzing the long-term role of transportation in society, or a particular important aspect of the role, that will improve understanding of transportation's relationships to spatial, social, and economic structures. Explore the motivations behind changing activity patterns, and the forces that influence their rates of change. Document this approach in detail in a Study Design Report. Describe in this report precisely what work is being recommended and offered to be performed to further develop a program of research to improve understanding of the role of transportation in society, in particular with respect to patterns of travel, location and development. Prepare and submit eight (8) copies of this report.

Item 2 - Master Program Schedule - Prepare and submit five (5) copies of a Master Program Schedule setting forth the items and tasks of work to be performed, as contained in the Study Design Report, establishing periods of performance and planned completion dates for each. Government responsibilities which impact contractor performance shall also be included. In addition it shall contain a projection of man-hours by task in monthly increments. The Master Program Schedule may be combined with the Study Design Report or submitted as a separate report.

Item 3 - Business/Cost Proposal - The contractor shall prepare and submit five (5) copies of its estimated cost and fixed fee, if any, for the proposed program contained in the Study Design Report on a Contract Pricing Proposal (Optional Form 60). The Optional Form 60 will be provided by the Government upon written request. The Optional Form 60 must contain your cost data in total, and be supported by other cost data in sufficient detail that they can be analyzed meaningfully. Subcontracting shall also be projected by the various cost elements and attached. Consultants shall be identified, together with their rates and expected usage. Any escalation factors must be identified together with rationale as how they were reached.

This Business/Cost Proposal shall include a Master Cost Schedule depicting estimated cost expenditures and estimated direct labor hours by task in monthly increments and cumulative, for the proposed program contained in the Study Design Report. In addition, the contractor shall provide such other administrative and proposal data that is required by the Government. Upon delivery of the Study Design Report, Master Program Schedule and Business/Cost Proposal the Government may, at its sole discretion, determine to open negotiations with the contractor to modify this contract to implement the appraoch contained in the Study Design Report. The contractor will enter into such negotiations and the Government shall have ninety (90) days from the date the Government advises the contractor of its intent to open negotiations to modify the contract.

The Government does not in any way obligate itself to modify the contract to implement the proposed approach contained in the Study Design Report.

Item 4 - Oral Briefing - The contractor will participate in a two (2) day workshop to describe the results of work performed under this contract. This briefing shall be held at DOT/TSC, Cambridge, MA.

## TIME OF PERFORMANCE AND DELIVERY SCHEDULE

| | |
|---|---|
| A. Commencement Date: | Date of execution of the contract by the Contracting Officer. |
| B. Completion Dates: | |
| Item 1 | Eight (8) weeks after commencement date. |
| Item 2 | Eight (8) weeks after commencement date. |
| Item 3 | Eight (8) weeks after commencement date. |
| Item 4 | Ten (10) weeks after commencement date. |

# 4. STUDY DESIGN REPORT SUMMARIES

## 4.1 Cambridge Systematics
Residential Housing and Location Model

### EXECUTIVE SUMMARY

#### Overview

This report presents a general approach for modelling all spatial phenomena, and a specific study design for the analysis of one major aspect of urban spatial change: the long-run interactions between transportation and residential location patterns in metropolitan areas. The strategy suggested is intended to address the possibility that significant changes in factors such as technology, fuel supply and demographics may dramatically alter the context in which future transportation and housing choice decisions are made.

#### Research Needs

There is a broad literature on previous studies of urban spatial location patterns and their relationship to transportation services. These include theoretical economic studies, large-scale planning models, small-scale transportation impact studies and disaggregate econometric analyses. A number of common issues, problems and lessons for the future can be extracted from these previous studies. In summary, these are:

1. The application of models to a hypothetical, idealized city has little practical relevance for policy analysis, due to the necessity of simplifying assumptions involving the spatial concentration of employment and travel time characteristics.

2. Land use models have typically distorted the importance of transportation factors by ignoring the wide range of tradeoffs with non-transportation factors (e.g., taxes, land prices, crime rates, public services, and recreation).

3. Previous approaches have relied on a static equilibrium model framework which is unresponsive to the elements of long-term dynamic change. Specifically, these approaches ignore the constraints on development from already existing buildings, infrastructure and neighborhood patterns.

4. The aggregate approach typical of land use planning models has not been sensitive to changes in the socioeconomic mix of the population or the corresponding changes in life style activity patterns with resulting policy implications for urban travel patterns.

A growing number of recent residential location studies indicate the importance of micro-level spatial model approaches which explicitly recognize the full range of non-transportation tradeoffs in a dynamic framework.

## General Framework

The Study Approach is based on a general conceptual framework encompassing all urban spatial phenomena. First, it is recognized that transportation interactions with society and the quality of life occur through several mechanisms on several levels. The Systems Mechanisms are:

- economic systems
- demographic systems
- social systems
- physical systems

Growth and change in each of the above systems occurs in the dimensions of spatial location distribution and activity sector distribution. Both classes of changes involve decisions by individuals and firms within the constraints of various input supplies and regulations, and are manifest on two distinct spatial scales:

- metropolitan/regional growth and inter-regional distribution
- intra-urban distribution.

The perspective embodied in the framework is a micro-level approach, in which the individual decision-maker (person, household, or firm) constitutes the basic unit of analysis.

- individuals and households
- producers
- regulators
- supplies of infrastructure
- service operators and transaction agents

Explanatory factors determining the decisions of each individual or firm are assumed to depend on changes in conditions that are exogenous to that actor. There are three basic types of variables:

- factors exogenous to the entire framework (e.g., geography, technology, federal policy)

- factors exogenous to the individual decision-maker but endogenous to other actors in the framework (e.g., land use demand, economic competition, travel characteristics)

- factors resulting from the interaction of different types of actors (e.g., prices for various goods, new construction, land development)

## Dynamic Structure

The key linkage between the decision-makers and the exogenous factors is the dynamic structure process. Choices regarding spatial locations and activities are represented as changes from an existing state

which are caused by exogenous events and decisions, including all previous choices and expectations regarding the future. In this way, all long-run forecasting is based on a proces of incremental changes over a number of limited length periods. The approach of "static equilibrium" is explicitly rejected in favor of a "marginal adjustment" model framework.

It is recognized that even within horizons of 30 years, it is not realistic to reallocate the spatial distribution of all urban activities or the distribution of labor and facilities among economic sectors. Given the durable nature of in-place building structures and infrastructure services, changes in urban spatial development and economic development will tend to occur in the form of increments from the current characteristics. Costs of new construction, structure conversion and investment capital all act as barriers to major reallocations of activities within cities and within industries. With this dynamic view, it is recognized that there is no long-term equilibration of supply and demand. Only the short-term adjustments of prices represent the movement of market forces at each point in time toward an ever-changing short-term equilibrium.

Any realistic forecast of long-term changes in urban spatial development patterns requires realistically-designed scenarios to represent expected shifts in the major exogenous factors. For purposes of long-term transportation planning and policy evaluation, the major classes of factors affecting urban spatial patterns include:

- o changing demographic patterns
- o economic implications of changing income and employment characteristics

- o future energy costs
- o rising land and housing costs
- o major technology changes

Proposed Analysis

The proposed study design applies the general "micro-behavioral" framework to define a specific set of econometric models for the analysis of long-run residential location change in urban areas. Specifically, the study focusses on the long-term relationship between the housing, employment and transportation decisions made by households. The approach is structured to be explicitly dynamic in the form of a marginal adjustment model representing changes in household choices over time. The model incorporates the following choices:

- o adjustment of workplace, or labor force participation
- o adjustment of residence location
- o choice of residential bundle, including housing and auto ownership (given a decision to relocate)
- o choice of mode to work

The model "feeds into" another set of models to predict short run travel choices for non-work trips, including trip frequencies, modes and destinations for various purposes.

The model structure incorporates a nested or recursive system that incorporates a sequential structure with explicit feedback between the levels of long-run and short-run decisions. Over a long run time horizon, changes in location choices lead to shifts in aggregate spatial development patterns, and thus change the characteristics of locational alternatives for subsequent decisions. A key aspect of this household

decision model is its realistic, behavioral orientation. It is designed to be sensitive to a wide range of transportation and non-transportation factors affecting residential location and transportation decisions.

The analysis model is operationalized within a micro-simulation framework which represents aggregate changes through the decisions of a longitudinal sample of households, whose diverse characteristics are reflective of population heterogeneity. The longitudinal sample of households and long-term transitions in its composition will be simulated from pre-specified probability distributions via a series of Monte Carlo transitions. The future changes in population characteristics and choice attribute characteristics are determined on the basis of explicit assumptions in various scenarios.

A series of four major scenarios are developed to represent alternative futures for a 30-year time horizon. These scenarios are organized into packages, each of which includes a set of projections for change in the following sets of factors:

- household formation, size, and age composition
- availability and prices of fossil fuels and other hydrocarbons used for transportation
- availability and prices of alternative fuels used for space heating
- housing prices and construction cost
- technological development for transportation
  - substitution of communications for transportation
  - electric cars
  - increased fuel economy of conventional vehicles

The need for a <u>geographically generalizable dynamic</u> model approach is an important issue. A basic premise of this study design is that the resulting analysis approach will be applicable for the evaluation of a broad set of transportation/spatial form interactions for national policy analysis. At the same time, it must be recognized that the interactions with which this analysis is concerned occur fundamentally on the intra-urban level.

Several national surveys are available which contain data on household mobility behavior and housing choices, but they are all deficient within the area of specific neighborhood locations and/or attributes of employment location and local travel behavior for the households. Local household surveys have the advantage that they overcome these data deficiencies and may be linked to additional zonal data on land use and locational quality characteristics. The availability of this additional data also makes possible tests of the model's temporal validity. Thus, the study approach calls for the application of the proposed forecasting framework to a small number of representative metropolitan areas, to produce long-term forecasts that can be geographically generalizable while realistically reflecting differential effects among different types of urban areas. The initial plan, as described in the study design, will involve the prototype application of the proposed model to a single case study city, in order to evaluate the value of this approach for further development and long-term forecasting analysis.

The approach developed in the proposed study is designed to be useful for the evaluation of the long-term impacts of a broad range of alternative national policies, including:

- highway and transit investments
- funding of transportation technology development
- aid to cities, including law enforcement and education grants
- community and neighborhood development grants
- housing subsidy programs

4.2 Research Triangle Institute
Methodology for Comparative Analysis of Urban
Spatial Structures

EXECUTIVE SUMMARY

Given the large quantity of transportation modeling that is concerned with the simulation and planning of future land use-transportation systems, it is surprising that so little attention is devoted to evaluation of efficiency and scale within existing urban spatial structures. In part this is due simply to the fact that planning is concerned with future conditions and therefore conditions that must be projected or predicted. More often, we suspect, it is due to the cost and inconvenience of collecting the data needed to calibrate models used in evaluations.

Still it would be nice if, like discussing different automobiles, we could point to certain cities more gasoline efficient than others in getting people to and from work and around town. We might even like to talk unambiguously with each other concerning the scale of life in different cities. "How far away are things there?" "How much driving do you have to do each year?" "How close are parks for the children?"

We must make similar judgements when we evaluate alternatives for urban growth and redevelopment, but how do we make them? What yardsticks do we use? One criterion that would be helpful in discussing the relative merits of existing urban areas is energy efficiency. Since energy consumption is paid for, records are kept and, though with some difficulty, information can be assembled to profile its use in different cities.

We would probably find that, despite the similarity of lifestyles, houses, cars, and buses, people in some cities use somewhat more gasoline than people in other cities, and we would want to understand why. To explain differences, we might turn to maps and compare the spatial

layouts of the different cities, the arrangement of commercial areas with respect to neighborhoods, and the configuration of transportation networks within land use patterns. But here our discussions would remain at verbal and graphical levels, because we lack any general quantitative methodology for describing and analyzing urban spatial organization.

Spatial distributions of populations, activities, and land uses across the city are the most tangible manifestation of transportation-land use interactions. Despite considerable attention to particular aspects of urban spatial structure, however, there exists no accepted method that is practical for treating the complex structure of real-world urban space as a web of interdependent distributions, i.e., a system of patterns. This stems in large measure from the inappropriateness of conventional data analysis techniques for quantifying the degree of spatial co-organization, areal association, or congruence between urban spatial distributions. To understand the role of transportation in bringing about desirable spatial patterns of land development within cities, rigorous methods for empirical analysis of urban spatial organization should be considered fundamental.

We propose to research an alternative method of spatial analysis designed explicitly for systematic characterization of the structure of spatial associations existing among urban variables (Ray, 1977). Our approach grows out of a particular combination, and in some instances, generalization, of mathematical concepts developed previously in the fields of information theory, trip distribution modeling, and the theory of multidimensional scaling. The pattern analysis method constructed appears well equipped for the study of transportation-land use interactions within and across cities. It enables more rigorous quantitative

characterization of specific urban spatial structures and makes possible comparative analysis of spatial structure across cities.

Unlike the product-moment correlation coefficients employed by conventional techniques, the measures proposed here depend in only a minor way on the sizes and number of the areal units selected for spatial analysis (e.g., blocks, block groups, tracts, zones). Thus, the proposed measures allow the use of powerful methods of multidimensional scaling for examining systems of distance relationships between distributions. Furthermore, it does this in a manner that is readily interpretable by transportation planners and policy analysts.

Pattern analysis enables quantitative comparison of spatial structures across cities. The method also allows statistical analysis of significant relationships of urban spatial structure to many other city attributes, including variables related to transportation, e.g., gasoline consumption, type of expressway network, type of transit system, density profile, etc.

Like other methods and models used in transporation planning, pattern analysis is hungry for data. However, since it requires only macro descriptions of population and activity patterns, there is more hope that data requirements can be satisfied.

Decennial census data have always supplied transportation planners with many of the inputs required for planning. These data have been indispensable to planning, especially as the large data collection surveys associated with the transportation studies of the fifties and sixties were found too expensive to be continued as components of planning methodology. Census records provide a wealth of data in standardized format describing residential population and housing patterns across all U.S. cities.

What has been lacking has been data describing daytime distributions of urban populations away from home, e.g., where people work, shop, and entertain themselves. Efforts by the Census Bureau in the area of place-of-work address coding give us considerable hope that much of this data is forthcoming with the 1980 Census. In fact, some data describing daytime employment distributions by tracts and by zones is already available in comparable fashion across many U.S. cities through present and past efforts of the Census Bureau.

These data result from the DOT-sponsored Urban Transportation Planning Package program associated with the 1970 Census, and the Travel to Work Supplement of the 1975 and 1976 waves of the Annual Housing Survey. The progress made by the Census Bureau in automating place-of-work coding for these surveys of the seventies lead us to believe that 1980 Census will yield a plethora of tract-level data across U.S. cities describing daytime employment distributions. Together with the population and housing data already provided, this represents the kind of database needed for comparative studies of spatial structure across U.S. cities.

Through this Study Design Program, we wish to test the feasibility and evaluate the benefits of pattern analysis as a method of studying the relationship between urban spatial structure and transportation facilities and demands. We will test the method using computer procedures that are in hand and using Census data on population, housing, and employment distributions that have been tabulated previously. We propose to conduct two sets of analyses.

The first of these will research the extent to which the proposed method allows characterization of urban spatial organization in a quantitative format useful for comparative analyses of spatial structures

across cites. We will focus on a analysis of the relative efficiencies of spatial structure over a sample of U.S. cities included in the Annual Housing Survey. Specifically, we will attempt to show that differences in spatial structure exist and can be measured and that measured differences can be related statistically to variations across cities in per capita gasoline consumption rates. To the extent that spatial structure is determined by transportation policy, we then have some evidence upon which to base arguements for policies associated with efficient spatial structures.

In our second component of research, we intend to demonstrate the richness of description that pattern analysis provides for the study and discussion of urban spatial structure. We will choose two cities and using 1970 Urban Transporation Planning Package data analyze spatial relationships existing among a variety of population, housing, and employment distributions. Through this set of analyses, we will attempt to show the usefulness of the analysis method as a means of characterizing the syntactical organization of urban space and exposing the relationship between transportation networks and development patterns.

4.3 Interchange (1)
Demography, Housing, and Transportation

## EXECUTIVE SUMMARY

### Problem Statement

An unprecedented wave of family housing growth, resulting from the coming of age of the post-war baby-boom generation -- by far the largest in history -- will greatly alter the demographic and housing context of transportation investment decisions in the 1980s.

> This giant wave of new families will offer a once-in-a-century opportunity to mold the transportation needs and habits of a generation. This opportunity will be lost, however, if federal and state governments fail to seize it.

As the baby-boom generation passes through the family-settlement stage of life (during the next 15 years), its preeminent need for shelter will be the major driving force shaping the landscape of metropolitan America. The nature of the new growth patterns will be subject to huge uncertainties, as a result of the enormous and unprecedented forces at work: Either highly dispersive growth (with rapid growth in the ex-urban areas) or much more concentrated growth (with large density increases in the close-in areas) may ensue, depending on a complex combination of economic factors, local growth policies, and various state and federal policies. These factors are not readily predictable.

There are increasing signs that the U.S. is in the

initial stages of what will be a severe family housing crunch, which will hit the baby boom hardest, and which will soon have to be resolved somehow. Because of the central role of housing in people's aspirations and expectations, a large-scale federal response seems very likely, although the form is very unclear. Many of the measures which might be used in reaction to the family housing crunch would have major impacts on the degree of dispersion in future metropolitan growth. Thus, the 1980s will pose very exacting challenges to transportation planners and officials who wish to use the growth-shaping potential of transportation investments to influence future growth patterns.

## Technical Approach

This proposal outlines a research effort which will result in a report documenting the forthcoming changes in housing and metropolitan growth patterns and in turn the implications for transportation policy. The report will describe how the (relatively predictable) demographic changes will interact with a range of plausible policy measures at the federal, state, and local level intended either to address housing problems or to influence growth patterns and with a range of plausible changes in economic factors. The total levels of transportation demand by major mode will be estimated from the data. Also delineated will be the degree of flexibility in transportation investment strategy which is warranted by the degree

of uncertainty in demographic, economic, and policy factors.

A case-study approach will be employed, using three metropolitan areas. The demography, housing market, and growth policies in each region will be analyzed, and the dispersion in each region will be forecast for each of several different <u>scenarios</u>, depending upon different assumptions about economic and policy factors. The generalizability of this research to other metropolitan areas will be demonstrated in the report.

Demography and demographic concepts play the most central role in our approach. The importance and relative stability of key demographic variables have been generally overlooked and underutilized in regional economic modelling and housing market analysis. Although we will incorporate a standard economic approach in the allocation of households to housing units, the basic demographic framework allows us to relate housing markets directly to housing needs rather than to demand, in contrast to traditional economic approaches. This is appropriate, given the mixed political-economic context which so greatly characterizes housing markets. Moreover, it is our basic premise that, in a severe housing crunch, government at various levels will intervene to meet people's needs even if demand, as traditionally measured, is insufficient to meet their expectations.

The central task of the modelling is to allocate popula-

tion and households among sectors of the metropolitan areas by age, taking account of both (1) the apparent strong preference of young families to locate in suburban and exurban areas, as indicated by actual behavior to date and by survey research on preferences; and (2) various considerations which may limit access to different sectors of metropolitan areas. These include such factors as local "no-growth" policies, actual land shortages, federal policies, and energy prices. To oversimplify, the modelling will address the questions of: Where will the baby boom settle? and What policies and economic factors will influence their choice?

Many of the policies which will have major impact on metropolitan growth patterns are intended to address totally different problems, including especially housing policies. Therefore, as inputs to the dispersion scenarios, we will analyze housing policies (especially at the federal level) and other policies (e.g., taxation) which can have major unintended impacts on growth patterns.

For each scenario, the long-term transportation implications of the resulting dispersion will be analyzed. This will be done chiefly through standard trip-generation techniques and an analysis of the appropriateness of various policies and investment requirements for the resulting transportation needs. Residential densities from the various scenarios will be related to the most suitable type of public

transportation sub-mode. Results will be interpreted in terms of feasibility of expanding existing public transportation services in the three metropolitan areas to be examined. The adequacy of current policies for transportation investments in these areas will be assessed in view of likely residential growth and population dispersion patterns.

Utility to TSC and UMTA

In short, we propose to provide transportation planners and officials with a clearer understanding of the demographic, housing, and growth-policy context of the transportation investment decisions of the 1980s.

In view of the magnitude and the unsettled nature of housing and growth policies for the remainder of the decade and the critical importance of these policies to transportation, it is imperative for the transportation sector of government to define a role for itself vis-a-vis the forthcoming changes in housing policy:

- To be called upon to deal with the aftermath of ill-conceived housing policies, which will have had unintended effects on regional growth and dispersion?

- Or to participate actively and informedly in a partnership with other federal agencies in designing a comprehensive approach to the problems of housing, growth policy, and transportation in order to channel the unprecedented forces of the next decade?

The research which we propose is intended to assist transpor-

tation planners and officials in adopting more the latter role than the former. Most importantly, only a pro-active stance can seize the once-in-a-century opportunity to mold the transportation needs and habits of a generation.

## 4.4 DAA Enterprises
Systems Dynamics Model

## SECTION 1: EXECUTIVE SUMMARY

### 1.1 Project Purpose

The overall purpose of this project is to improve our understanding of how transportation influences long term metropolitan spatial patterns through complex interactions of social and economic forces. The project involves the development of an innovative approach in this broad area which will advance the state-of-the-art of urban transportation policy analysis. This project also involves a demonstration of the feasibility of this innovative approach so that it may later be applied to a variety of metropolitan areas in order to gain an understanding of the long term impacts of major transportation and related urban policies.

The project will concentrate on the formulation of a generic dynamic feedback simulation model, the parameterization of the model, sensitivity testing of the model, and policy analysis with the model. The Metropolitan Simulation model, METSIM, will relate changes in the metropolitan transportation system to changes in aggregate urban economic, fiscal, physical, and demographic characteristics. The model will focus on the long term feedback nature of the basic mechanisms underlying these changes and on the effects of broadly defined transportation and urban management policies. The project will build upon previous work in the areas of land use forecasting, system dynamics, industry location and urban evolution. The project will make use of the experience of DAA in the formulation of generic feedback simulation models and build on the state-of-the-art advances DAA has pioneered in its regional utility simulation model for Saudi Arabia. The model will include a number of innovative aspects.

The project will draw on a wealth of information and practical experience through the use of an advisory group of recognized experts in transportation, economics and the social sciences. The advisory group will meet periodically for the purpose of ensuring that the resulting model is both technically correct and useful for policy analysis.

## 1.2 Method of Approach

### 1.2.1 Use of the System Dynamic Paradigm

The innovative approach to societal-transportation interactions proposed in this study will be guided by the systems paradigm, which includes the following steps.

The first step is the problem definition. A lucid description of the problem behavior which one would like to change or control is absolutely essential, since this problem behavior and its descriptors become the focal points for the study.

Second, the basic mechanisms which cause the system to behave in this problematic manner are defined. This set of basic mechanisms is the initial "dynamic hypothesis" about how the elements of the system interact to produce the problem behavior. The basic mechanisms which form the dynamic hypothesis for this study will be discussed in detail below in Section 2 of this report.

Third, the geographic boundary and time horizon of the system are defined. The geographic boundary should be large enough to include all of the basic mechanisms. The system behavior should be simulated over a sufficient period of time to allow proposed policies to have an effect.

The fourth step is to construct and test the formal simulation model. Equations are written for the simulation model, data necessary to parameterize the model are collected, and a

series of sensitivity, validation and policy analysis runs are performed.

The use of this organized "systems approach" permits an in depth and comprehensive analysis of very complex systems. For models constructed to elucidate the causal nature of real systems, emphasis is placed on testing alternative dynamic hypotheses, the sensitivity to uncertainties in the input data, and the robustness of the model behavior modes.

### 1.2.2 Problem Definition

The problem of transportation in metropolitan areas is inextricably linked to what has become known as the "urban problem". The urban problem is defined in terms of five sets of changes which have taken place over the last several generations in all of the major urban areas in the United States. These five sets of generic trends, and the role of transportation in augmenting or ameliorating these trends will serve as the focus for this study. These trends are broadly defined as follows.

Demographic change is always associated with urban decline. As a result of white upper-and middle-class families migrating to the suburbs, the remaining inner city population contains an increasing fraction of blacks and other minorities as well as older people. Average family incomes of those people who remain in the central cities are significantly lower than incomes of people who have migrated to the suburbs.

Economic change that has been occurring in urban areas since the 1940's involves the relocation of commercial, industrial, and retail business activities from the central city to the surrounding suburbs. An increasing fraction of new industries in the metropolitan areas have located in the suburbs instead of the inner cities.

Fiscal change is a direct result of the demographic and economic changes. The urban infrastructure and service needs of the remaining inner city population have been increasing on a per capita basis, while city tax bases have been shrinking. This deteriorating fiscal situation has made it even more expensive for cities to finance capital projects through bond issues. Physical change, such as decay and crowding dominate one's perception of the inner city. The depreciation and obsolescence of buildings, factories, and houses is an inexorable process. Progressively more and more maintenance is required to keep city structures functional while the technologies, architectures and factory production systems become increasingly obsolete. As inner city land becomes increasingly occupied by deteriorating structures, it becomes more difficult and expensive to build new houses and buildings. At the same time, space for transportation facilities, parks, and other civic infrastructure is no longer available.

Social and psychological change reflects the deterioration in urban quality of life. Interracial tensions, violent crime, and an ubiquitous drug culture have become a real part of the lives of many inner city dwellers. In most cases, the inner city public education system is shunned by the upper and middle class population. While the physical deterioration of the inner city is simply unaesthetic, the city suffers from a disproportionate share of real health hazards in the form of air and noise pollution and social congestion.

Metropolitan transportation systems are generally assumed to have had a significant impact both upon the time and the spatial dimensions of the urban problem. Metropolitan rail transit, roads, and highways have generally facilitated the flight of increasing numbers of upper and middle socio-economic

class people and businesses to the suburbs. It is the transportation system that allows the increased segregation of jobs and homesites, and which itself becomes congested as more and more people opt for commuting to work between the suburbs and the central business district. As new roads are built, people move further into the suburbs so that feeder roads become congested beyond their carrying capacity.

The main feature of the transportation problem is the congestion that occurs during rush hour along commuting routes between the suburbs and the central city. Later, this is accompanied by congestion along feeder roads in the outlying areas and congestion along ring roads linking centres of population density and industrial activity in the suburbs. To a lesser extent, the transportation problem can be viewed in terms of the reliability of mass transportation, personal safety, access to transportation facilities, especially among lower income groups, and the relative impact of different modes on the economy, the energy situation and the environment.

The central focus of this project will be on the feedback interactions between the transportation system and the economic, demographic, physical and fiscal dimensions of the urban problem. The fundamental assumption upon which this project will be based is that policies which affect the transportation system will have a long term effect on the evolution and spatial distribution of jobs and homesites within the metropolitan region. The complementary assumption is that policies which affect the location and spatial distribution of businesses and homesites will affect the adequacy and function of the transportation system.

The interrelation of some of the various dimensions of the urban and transportation problem as discussed above is shown

schematically in Figure 1. The message of Figure 1 is that one cannot increase understanding of the effects of transportation on society unless one simultaneously considers a number of the most important generic changes that society experiences while the transportation system evolves. In particular, if one hypothesizes that the metropolitan transportation system had an important effect on suburbanization in American cities, then other elements in the urban environment which have also affected suburbanization trends (and therefore the transportation system) should be included in the study.

### 1.2.3 Scope of the Proposed Study

The basic mechanisms, shown below in Section 2, will serve as the conceptual framework for this simulation study. The basic mechanisms constitute a dynamic hypothesis about the causes of the urban and transportation problems and about how various policy alternatives will affect the system. The fundamental nature of this model framework is that the basic mechanisms form feedback loops and thus the resulting behavior of the urban and transportation system is the result of the interactions of a large number of feedback loops.

The model will include three levels of aggregation: 1) the metropolitan region which determines the overall growth of new business and net migration in the region; 2) a number of zones within the metropolitan region which compete for the location of new and migrating industries and; 3) a number of town clusters within the zones which compete for the location of residences for the in-migrants and people who change residences within the region.

The model will be parameterized for the Boston metropolitan region as a first case study. This means that it will include the City of Boston as well as approximately 101 towns and cities which constitute the standard metropolitan statistical

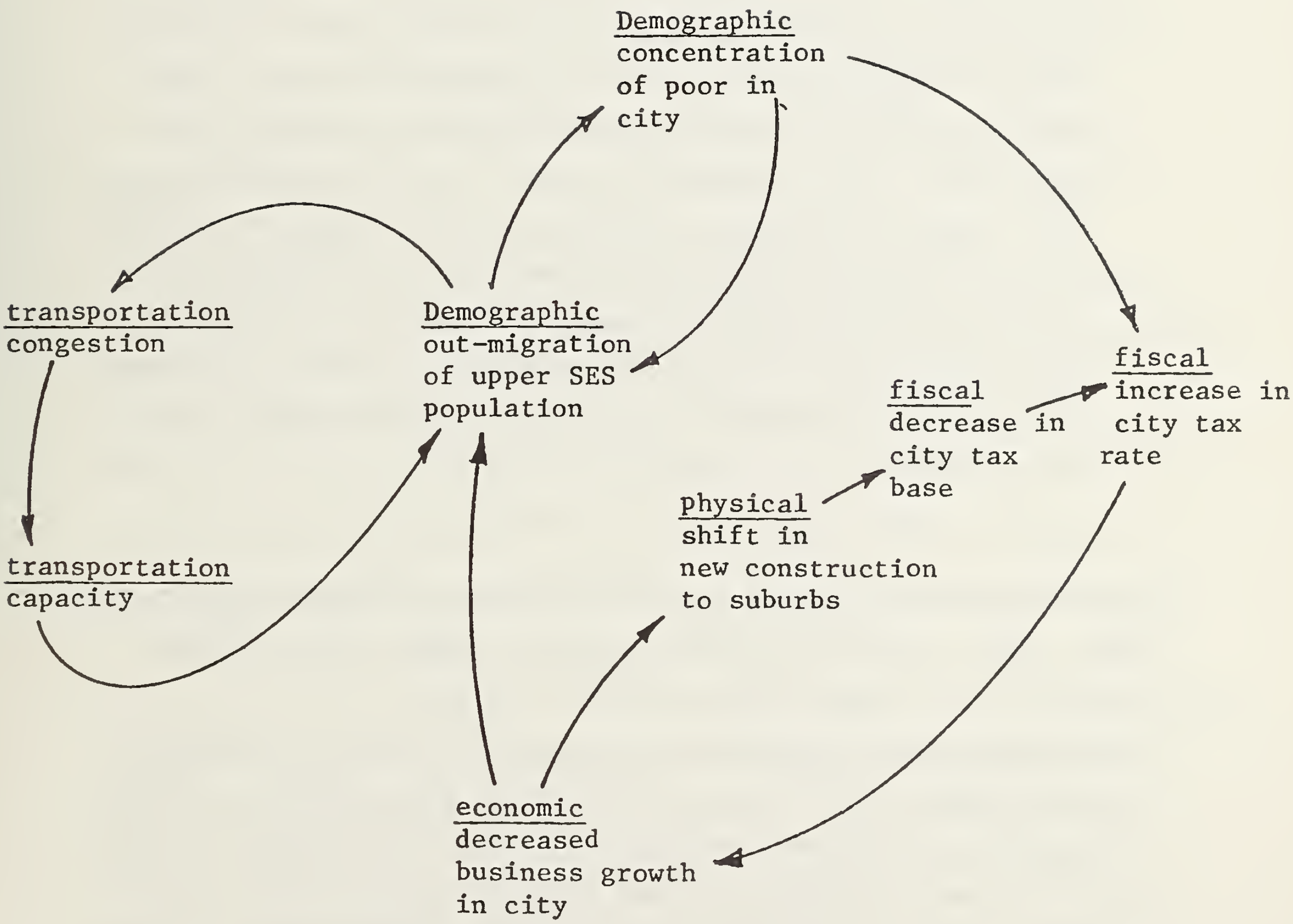



FIGURE 1: Interrelation of the Transportation and Urban Problems

area of Boston. Therefore data for the model will be gathered from a variety of sources including censuses, metropolitan transportation surveys, and other research project reports specific to the Boston area or to the role of transportation in urban evolution.

The study time horizon will be 150 years which will enable the model to simulate 100 years of past urban evolution in addition to simulating the effect of policies 50 years into the future. This long time horizon is dictated by the time constants of the important basic mechanisms within the system which include the depreciation of building structures, the time it takes for urban and suburban areas to occupy open land within their jurisdictions, and the time it takes for urban and transportation policies to have a significant effect on the spatial distribution of population and businesses in the metropolitan region. The text of this study design includes a more detailed description of the dynamic hypothesis, data sources and adequacy, as well as intended model testing and application.

## 1.3 Utility of the Model for Policy Analysis

Three types of policies will be analyzed with the proposed simulation model. These are transportation policies, urban policies, and synergistic transportation and urban policies.

Transportation policies include policies which seek to influence suburban access, modal split and cost of commuting, and the effect of transportation systems on business growth in the region. Urban policies to be tested will include physical policies which affect the demolition and renovation of buildings, fiscal policies such as tax relief, land use and zoning policies, and socio-economic policies.

Synergistic policies which combine transportation and urban programs will include such things as using the transportation system to aid in the restoration of the inner city, combining mass transit and urban social welfare programs, and suburban-oriented industrial or transit access programs.

The model will be specifically aimed at analyzing the effects of long term development policies for such federal agencies as the Department of Transportation, the Department of Housing and Urban Development, as well as regional, state and metropolitan planning commissions. By using this model these audiences will be able to analyze the long term impacts of significantly higher gasoline prices in the next 50 years or the real advantage of mass transit modes in suburban areas. Also of interest will be the utility of using the transportation system as a mechanism for inner city revitalization, the relationship of transportation to the mobility of the poor in metropolitan areas, and finally, whether transportation development policies will serve to hinder or enhance policies directed toward ameliorating the generic physical, fiscal, demographic and socio-economic problems of the inner city.

## 1.4 Data Availability

The primary source of data for this study will be the library of the Metropolitan Area Planning Council located in Boston. The council has collected and organized a vast array of census, tax, manufacturing, and transportation data from each of the towns within the planning region. Although some minor aggregation of this data may be necessary, statistical analysis will not constitute a major part of this study. DAA has assembled an extensive bibliography of empirical research on urban job and residential location, urban evolution and urban transportation. In addition, the study advisory group will advise on new sources of data as well as render judgments

on the suitability of one source of data versus another.

## 1.5 Model Testings and Validation

Model testing will include five tasks. The first task will be to replicate the historical behavior of the Boston metropolitan region over the past 100 years. The goal will be to achieve a qualitative agreement between the historical statistics and the major model state variables.

The second task will be an extensive sensitivity testing of the model. The goal of this task will be to find out whether uncertainties or errors in the model data will have an unacceptably large impact on the model output. Next, the robustness of conclusions derived from policy simulations in light of uncertainties in the data and variations in the exogenous inputs will be determined. Next, a wide range of policies will be simulated. Finally, mudgments as to the validity of the dynamic hypothesis will be made, with the aid of the advisory group, taking account of the whole range of model tests as well as empirical support for each structural element in the model.

## 1.6 Difficult Features and Issues to Resolve

The difficult features of this project fall into three broad categories. All of these issues will be resolved with the aid of the advisory group. The first set of issues are called structural issues which concern modifications or additions to the proposed dynamic hypothesis. Questions in this area primarily concern the detail necessary to simulate the transportation system. The next set of issues concerns the availability and suitability of data for the model. Finally, issues concerning the exact specification of certain system variables will be resolved.

## 1.7 The Project Advisory Group

In addition to other innovative aspects of the project to be discussed below, DAA is proposing the creation of a panel of

experts who will work with us throughout the course of the project, critiquing our efforts, suggesting new and different ways for including data in the model, rendering judgments during the validation of the model, aiding in the determination of the realism of policy simulations and, finally, focusing on increasing the model's utility to policy makers. The advisory group will be composed of recognized experts in the general field of "urban studies" and will represent a wide range of formal academic specialties and practical experience.

Individuals to be included in the special advisory group will have specific expertise in the areas of urban geography, urban economics, urban sociology, transportation planning and urban government and administration.

The advisory group will meet periodically at the offices of DAA throughout the course of the project for a series of extensive and in-depth seminars. Among others, the advisory group will include Professor Alan Altshuler, who is presently Head of the MIT Political Science Department and was Secretary of Transportation for Massachusetts from June 1971 to January 1975 and Professor Jerome Rothenberg, who teaches in the MIT Economics Department and who has written extensively on urban economics and transportation.

## 1.8 Innovative Aspects

In the field of urban systems modeling, the proposed simulation model is the first feedback dynamics model of the urban transportation system capable of showing long term evolution of the metropolitan area. While one or more previous urban system models may have included some of the characteristics of the simulation model proposed here, this is the first simulation model which is: 1) constructed according to the system dynamics paradigm; 2) spatially disaggregated; 3) designed to include a major transportation sector; 4) designed to be generic in structure; and 5) applied to real metropolitan data.

A number of fundamental differences exist between the proposed simulation model and the Community Analysis Model developed by David Birch at MIT. The differences include: 1) the fundamental purpose of the models; 2) the emphasis on transportation and transportation feedbacks; 3) the inclusion of fiscal policy in the model; 4) the structure used to simulate business location in the region; and 5) the time horizon of the models.

## 1.9 Future Applications Beyond the Scope of This Study

The time limitations for the proposed study make it necessary to limit the application of the metropolitan simulation model to only one area. Future applications of the model could include other metropolitan areas, as well as entire regions including a number of cities. Two additional tasks which should be undertaken in the future include developing computer programs to replicate the generic model structure as well as the training and indoctrination of urban and transportation policy makers.

## 1.10 Documentation

The contract deliverables will include program flowcharts, documented equation listings, a model description, and tables and plots of simulation run outputs (see Section 10.1 and Part II: Work Schedule). This documentation will be sufficient to allow one to understand the model structure, replicate the model runs and experiment with the model.

## 1.11 Project Schedule and Business Proposal

The project schedule has been submitted as Part II of this technical proposal, while the project business proposal has been submitted under separate cover to the project sponsors at the Transportation Systems Center.

4.5 Futures Group
Probabilistic Systems Dynamics Model

## EXECUTIVE SUMMARY

Over the past two months The Futures Group has been exploring an analytic approach to improve understanding of the complex interactions between transportation and society. In this work, our objective has been to develop an innovative approach which would, when implemented

- describe impacts on the structure of U.S. society of major, long-term improvements in urban and intercity, public and private, passenger and freight transportation.
- determine the consequences of no major improvement in transportation infrastructure in terms of the value of mobility to society.
- compare relative advantages of cities and regions based on their unique transportation characteristics.
- find synergistic policies and actions beyond transportation development and investments that might be used to complement transportation improvement for marked benefits to society.

The relationship among transportation, social, economic, and ecological developments is extremely important, complex, and often obscure. Furthermore, future events that are unprecedented may be crucial to this relationship. The objectives outlined above are, therefore, difficult to satisfy. Nevertheless, it is extremely important to pursue this work despite its difficulty because the consequences of policy--including no action--may be debilitating or severe in terms of their impact on business and lifestyles.

The problems faced in our present preliminary design tasks were these:

- Is any approach to this project likely to meet with success?
- If so, what approach seems to offer the most promise?
- How might this promising approach be most effectively implemented?

The answer to the first question--is any approach to the project likely to meet with success--is almost certainly, "yes." We believe that it is possible to construct a model that will display the interaction among transportation, societal, economic, and ecological factors with sufficient precision to forecast their mutual evolution in the presence of policies designed to affect one or most of them. Furthermore, we are convinced that such a model can be validated in a way that will provide confidence in its ability to reflect the effects of policies under test. Our judgment about the feasibility of such a model is based on not only a review of the recent modeling literature, but also preliminary attempts on our part to construct the framework for such a model.

The most promising approach, it seems to us, is the construction of a probabilistic system dynamics (PSD) model, initially at the regional level. We considered both economic and system dynamics models as alternatives to PSD. Both were rejected because they are essentially extrapolative and our problem is <u>not</u> to determine where the past suggests we are moving, but rather to discover the effects on past trends of future unprecedented events and policies. Therefore, we had to find a technique that would permit us to explore how past trends might be modified in the presence of sets of future events and sets of policies. Such future events and policies are the essence of the future and will, in effect, determine the outcome of the relationship among transportation, societal, economic and ecological development. While it is true that an economic or a system dynamics model may be run many times, each with another exogenous assumption, the methods do not lend themselves to testing the outcome of interactions in the presence of a large number of potentially simultaneous events. Therefore, we elected to recommend PSD as the modeling tool.

In the PSD process, a system dynamics model is first constructed. This model depicts the interrelationship among key variables within a bounded system. The model is constructed using historical data and validated by comparing the outcome of the model to actual data within another historic period. Other validation approaches are possible, of course, including observation of the dynamic response of the system to past shocks, and the plausibility of forecasts. However, as noted above, we will not be satisfied with a validated system dynamics model since, in effect, it only extrapolates past relationships into the future. A robust solution must include explicit consideration of unprecedented events and policies and their consequences on the otherwise extrapolative solution.

In PSD, therefore, the next step is to form a list of events and policies that might be present in the future time period under consideration. These are expressed in terms of probability versus time. Then the impact of each event and policy on model variables is estimated. Furthermore, the effect of changing model output on event probabilities is estimated. Finally, estimates are provided as to the conditional probabilities of events and policies on each other. With these three new "loops" available, the model is run as follows:

- The system dynamics portion of the model is run for one year and then stopped.
- The event and policy probabilities are computed at that year.
- Using random number "draws," each event and policy is decided: in other words, it is taken to either happen or not happen at that particular time.
- When an event "happens," other event probabilities are adjusted to reflect the occurrence of the first.
- For those events that occur, the impacts on the model coefficients and equations are entered and the system dynamics portion is run for another year.

- This cycle is repeated until the entire time interval of interest is covered, constituting a single run of the model.

- Then the procedure is repeated many times so that a full range of model output may be obtained; in other words, the model output is probabilistic.

Policies can be tested, of course, by varying their probabilities. Usually policies appear with either a zero or unity probability, representing their exclusion or implementation.

In terms of scale of application, we selected the region as an appropriate level of aggregation for a PSD simulation because

- to have treated the United States as a whole in the model would have severely blunted interesting and important nuances of policy impact and relationships.

- the region is expandable, but with the insight gained on a particular region, the lessons could be applicable to other regions. However, the next step in the process may well be constructing recalibrated models of other regions which then are linked.

- having built a model of the region, models of further disaggregation could be constructed to simulate smaller geographic areas within the larger domain.

Of all of the regions within the United States, it seemed natural to select New England for study. Both The Futures Group and the sponsor are located in this region; data centers are easily accessible to us; our judgments about transportation and their relationship to other factors are based on first-hand experience. Furthermore, the region is under severe stress because of many factors including migration, the high cost of energy, changing business characteristics, economic uncertainties, etc. Therefore, a successful outcome of the modeling approach here would provide important, substantive information to regional planners.

As for the implementation of the model, we see it as addressing two major subsystems. The transportation subsystem will be described in terms of

various modes of transportation, the kinds of services provided by these modes, the markets to which these services are presented, and the various purposes of the transportation utilized. The social system model will include or be influenced by consideration of people within the region and such factors as migration, income and health; land-use patterns and accessibility; communications techmology and its availability; of course, the means of transportation; economic production activity including employment; public and private finance; materials, both artificial and natural; technological evolution, and in particular its effect on the productivity of key industries within the region; energy availability and price; waste and its effect on air, water, and land pollution; changes in societal structure including labor, community, family, etc.; and, to the extent possible, changes in lifestyle and values. This list is incomplete but serves to illustrate the scope of the model. The model is not, of course, yet constructed. Nevertheless, we did complete two principal causal loop diagrams to illustrate the first-order interconnection among the various elements of the functional model. These loops involve first, the business and environment interaction, and second, the transportation/communication interaction. The causal loops are illustrated in the body of our report.

We estimate that the New England regional model will require approximately 1.25 man-years to complete. This work will be under the direction of W. Donald Goodrich, Manager of Technical Studies at The Futures Group. Mr. Goodrich has spent more than 15 years in the analysis and planning of urban transportation systems, emphasizing technical, operational, and economic feasibility studies for products and processes of the future. He will be assisted by other members of The Futures Group staff including Dr. Ralph King, who is an expert in operations analysis and who will, in this work, be charged with the actual

construction of the PSD model. Dr. King brings to this study valuable experience in constructing models of similar complexity for other applications. The Futures Group has provided PSD models to a number of clients over the past several years. These models focus on topics quite different than proposed here but, which, nevertheless involve economic, technological, and market interaction with external events and policies. This modeling experience has equipped us with the specific knowledge required to build models of the sort proposed here, both in terms of conceptual familiarity, and knowledge and experience with the required computer tools.

In the design of our study we were concerned with problems of user/model linkage. The problem is familiar enough: designers of models build them, and demonstrate them to potential users who should find them attractive. Yet, something "falls in the crack" and many models, despite their potential value, go unused. There is often a mismatch between policymakers and modelers. We hope to avoid that difficulty in several ways:

- PSD is less of a "black box" than many other models; the coefficients of the equations have physical significance and the events and policies to be included are external to the model and may be easily understood and modified by any user.

- We intend to have frequent communication with TSC during the study.

- The model itself will be delivered to TSC in more than one way. First of all, we intend to construct the model using a national time-sharing network. Thus at the completion of the study, TSC could, if they wish, simply take over the model on the existing computer system. Second, a complete computer code will be included in our final report.

We hope that our feelings of enthusiasm are clear to readers of this report. We believe that the work is important, perhaps essential, and that the work can be done. We look forward to the next step.

## EXECUTIVE SUMMARY

Large amounts of research and development have been performed on urban transportation problems. Most of the work has been carried out in a partial context, although significant amounts of work have produced some results in relating transportation to overall urban development. Enough work has been done and enough problems have been faced to produce a general recognition that there is a complex interdependence between the several levels of public decision-making and the vast amount of atomized decision-making of firms, households, and individuals in the private sector. Some means of properly abstracting these interdependencies in a manageable and sufficiently specific way would provide both public and private decision makers with an enormously useful tool. It is this recognition that led to the research already done on transportation and urban development.

Most attention has been given to land use/transportation interactions in past research. However, most approaches still are incomplete in one way or another. For example, there is a general lack of consideration given to how housing markets, local production and trade activities and external trade activities interact with each other to produce decisions on levels of transportation services and facilities. Furthermore, work to date has not adequately allowed an

analysis of how intergovernmental public decision-making and investments in transportation change relative efficiences in an urban economy, viewed as an income producing and distributing unit.

An adequate model which is both comprehensive enough to be complete, and concise enough to be doable, does not exist. Lack of a standard approach in the literature and profession and the current TSC search for innovative approaches both attest to this fact.

In summary what is needed is an approach which incorporates both a firm theoretical structure and basis, with empirical findings. Also a multi-sectoral approach is required to recognize all the major activities transportation affects directly or indirectly. We propose such an approach. Considerable development work has already been done. Important research lessons from previous research efforts have been incorporated in our model. This means that unlike most previous urban models, ours does not attempt to construct theory "from the ground up". Rather, our model provides a framework whereby existing theories and findings, including those embodied in previously developed models, may be incorporated. The basic equation structure for the entire model is fairly compact. There are separate equation sets for the following activities:

Social Utility

Regulatory Constraints

Public Revenue

Public Service Budget

Transportation

Housing Market

Production

Consumption

Wages and Prices

Land Market

In sum, these describe an urban economy. The model incorporates adjustment processes in the individual markets. Many variables are common to two or more equation sets and lagged variables are included. It is an allocation model in the sense that activity levels in zones which sum to the urban region are estimated by the model. Once in place with data for a representative urban area, the model is capable of tracing through, over time, the effects of transportation investments on the other major sectors of an urban economy. The model will also estimate the effects of non-transportation investments or regulatory actions on transportation.

The most innovative feature of the model as contrasted with other urban simulation models, is its market clearing mechanism which relates all the sectors with each other. It is fundamentally an economic model.

In consideration of the objectives stated by TSC, the following are the features of the proposed work which appear to be of greatest significance.

First, by treating the market for transportation within the context of an elaborated set of economic relationships, a wide variety of public policies and actions may be investigated which affect transportation, sometimes in indirect and possibly counter-intuitive ways.

Second, the development of this model would produce an investigative tool which may be employed to examine the implications of various theories and empirical findings related to the spatial arrangement of activities within urban areas under a wide range of conditions in the urban economy -- the model would synthesize disparate research findings.

The model is to be operated as a heuristic device, i.e., one by which the accumulated understanding, as well as conjecture about the workings, of the land market and its relationship to transportation can be incorporated in a coherent way. Operationally, the necessary flexibility for achieving these aims is to be achieved by structuring the model as a set of modules. These may be given alternative specifications, and their linkages rearranged to represent, respectively, alternative behavioral hypotheses and causal sequences.

Third, the model depicts the urban economy in terms of

an interrelated set of markets. The spatial arrangement of activities pertaining to those markets is determined through the land markets -- the market for location and areal extent of occupancy by activities.

The model as specified in this report, while self-contained, is viewed as being the first stage of a development which would see subsequent modifications and refinements in the form of greater elaborations of the behavioral equations, of the data employed in model simulation, and of the computational system, including devices for greater user-orientation.

The objectives of the first stage of development may be summarized as:

- first, the development of a workable system for simulating arrangements of scenarios consistent with policy and other exogenous alternatives;
- second, the identification of the properties of the model as a working system;
- third, to demonstrate that the model is capable of yielding results useful to the client.

The objective of developing a workable system has been dealt with in three respects. First, in terms of system development, the approach which we intend to implement and establish is a core of optimization modules which become a central driving force of the model. The capture of data at a level of micro detail implied by the model equations represents a second aspect of system development. The prob-

lems have, to a considerable extent, been circumvented by the use of the device of examining an urban area with composite characteristics, i.e., one which typifies the distributions of characteristics to be found in an "average" urban area.

The second major objective of the first phase is to identify the properties of the model as a working system. This involves first, the examination of:

- the stability properties of the model as well as its sensitivity to alterations in the hypotheses embodied in the model, i.e., the formulation of the equations and their interrelationships in the overall solution;

- variations in speed and extent of behavioral reactions, i.e., the parameters of the system;

- the levels of both exogenous variables and initial starting values for endogenous variables.

Second is the question of ease of use of the model. Third, while there is in concept the potential for posing a large number of alternatives about urban growth, policy, etc., the mechanics of constructing alternative simulations may be facilitated by the existence of a set of structures, each embodying a particular base case.

As a fourth major objective the model must, of course, be capable of yielding useful results for the client, if it is to be more than a research tool. There are two aspects to this point. First, the simulations must be plausible. This means that they must be built not only on real-world data but also (a) that the model equations and optimizing

routines reflect the essential characteristics of the markets which they represent and (b) that the model parameters be accurate. The behavioral relationships are based on models which have been employed in research studies in urban economics and other micro-economic topics. For each of the individual modules substantial numbers of studies are available for this purpose. The settings on the values of the corresponding parameters, which must be judgmental, can be tested for their plausibility only by examining how well the output levels of the model simulated as a whole corresponds with what might be identified as long run levels in actual urban areas. Finally, in order for the results of these simulations of an idealized urban economy to be plausible enough, so that U.M.T.A. is willing to apply the conclusions with confidence to the real world, it is necessary, as a practical matter, to be able to test the results. It is suggested that historical growths of individual urban areas, as well as cross-sectional comparisons of the urban areas, of different sizes and characteristics at a point in time could be used to validate the model. The second aspect in the consideration of the usefulness of the results of the model is the question of whether it enables UMTA to perform simulations and derive conclusions which are relevant for the problems with which it is faced. Several types of scenarios are outlined illustrating ways in which UMTA might employ the model for guidance

in policy considerations. These or other scenarios might be employed in a series of trial simulations with the model in the course of the project, the choice of scenarios depending upon discussions between the builders and the clients.

Within the project being proposed it is intended to study the transportation module with a view to further elaboration. This is not to preclude the possibility, however, that as a result of operation with the model, other aspects may not be recognized as having greater priority.

In adapting a model such as the present one which contains an interrelated set of behavioral equations to a specific computational system, a number of issues need to be resolved by the model builders. These issues, almost inevitably, involve not only decisions among alternative computational methods for implementing the behavioral relationships as formulated, but also some refinement and possibly re-specification of the form which those relationships take.

The issues which will have to be faced and resolved by the model builders in the process of systems design and implementation involve a hierarchy of considerations. First, and most generally, is the question of the extent to which optimization models would be employed in alligning the various markets which constitute the model structure, versus the use of heuristic devices whereby parameter and other adjustments can be made so as to obtain stable and reasonable results.

From this general problem stems the subsidiary one of the general form of the structure of the model -- briefly, at one extreme a general-equilibrium solution in which ratios of marginal utilities to prices are equalized, versus a decentralized system of markets and quasi-market allocation mechanisms in which a stable solution is possible essentially because the components of the system are only partially linked.

Considering this general problem in the context of the specific model with which we are dealing, we discuss an initial specification in which market and other allocation mechanisms are presented as a series of modules to be run primarily recursively, with some amount of feedback and adjustment. We further outline an approach for regrouping the modules in order to move somewhat toward a general-equilibrium solution. A specific formulation which will be chosen in the course of the work on the implementation project involves a choice as to the relative extent to which one of two solution methods is to be employed.

The model is viewed as potentially assisting UMTA in its policy analysis as an element of its long term strategic planning. It is designed to examine major questions as to alternatives available or potentially available to UMTA, and to the impact on the efficacy of its policy instruments as the result of environmental changes. These changes might be

in the features of urban growth or in other public policies which have cross-effects on UMTA policies. Some of the recurring questions which UMTA seems likely to address with the model include:

- Financing
    - level of funding for transportation
    - alternative formulas for funding
    - balance between capital investment and operating funds
    - distribution of funds among urban areas by size, region, socio-economic characteristics, fiscal capacity, etc.
- The cross-impact of other Federal and State Programs, including:
    - housing subsidies
    - public facility grants
    - general revenue sharing
    - employment-related programs
- Technological change
    - substitutes for transportation
    - plant size and location
    - industry mix and input requirements
- Demand determinants
    - household sizes and incomes
    - labor force participation rates and leisure
    - work scheduling over the day

In addition to the above questions which may be assumed as part of the routine policy analysis activity of UMTA, the model would allow the examination of many new problems affecting transportation as they arise, such as changes in labor force participation, price inflation in housing, technological change, etc.

## 4.7 University of Illinois
Societal Linkages Model

### EXECUTIVE SUMMARY

The purpose of the research program that is proposed in this report is to develop a transportation policy and planning methodology that utilizes the functional role of accessibility as the basis for establishing transport requirements. "Functional role" is defined as the linkage between the consumer and the output of the production system (access), as well as the freight and person movement that is needed to produce the output (production). A unique property of this approach is to employ a quality of life criterion as a basis for analyzing the effects of transportation and determining the requirements for transportation. The proposed model structure is an abstract modal approach designed ultimately as a policy and planning tool. It is conceived as a strategic model rather than a tactical one of which UTPS is an example.

The underlying concept involves two considerations. One is the disaggregation social organization into a set of societal systems which represent the sources of goods and services from which the population can obtain satisfaction of essential as well as discretionary needs. Two is the effectiveness of these institutional arrangements as measured by the consumers' ability to obtain the specific goods and services that define their actual quality of life.

Thus, one basic element of the proposed approach is the taxonomy of consumer needs and desires, which is the underlying determinant of the output of the production system. It is our view that the societal systems are definable by the way in which consumers dispose of their resources and in the way in which government provides direct support for services. Consequently, one can look at two basic economic measures to identify these societal systems. One is the Personal Consumption Expenditure and the other is Government Purchase of Goods and Services. As has been noted (Baker et al, 1978), there are ten such societal systems involving expenditures that account for 2/3 of the GNP. These systems can be classified into three groups, and are shown in Table 1. It should be noted that each of these systems is presumed to provide an element necessary to or desired by members of a society to insure their security, safety and satisfaction. It is how well these systems satisfy needs that determine what is called the quality of life.

Although the concept "quality of life" has been used for the past 20 years in a descriptive sense, it has received considerable attention in the social and behavioral sciences as a basis for social accounting (United Nations Report, 1954; McGranahan, 1971; Milbrath, 1979). The term has been developed, as a construct, from both a global "consumer" standpoint and a societal system standpoint. The first has been concerned with individuals' overall satisfaction with the elements of their lives. Several cross-cultural studies suggest that individual's evaluation of "quality of life" is a relative measure of their outlook on life (Galnoor, 1971; Guttman, 1971; Milbrath, 1979)and in this sense

Table 1
Societal Systems for Providing
Quality of Life Goods & Services

A. Life Support

1. Food
2. Clothing
3. Shelter
4. Health Care

B. Protection

1. Public Safety

   a. Fire
   b. Police
   c. Natural Disaster-Civil Defense

2. National Defense

C. Enrichment

1. Education

2. Culture
   a) Arts
   b) Music
   c) Theater

3. Religion

4. Recreation

is a useful measure of short-term trends. However, because subjective satisfaction is relative, it does not appear highly correlated with the quality and quantity of goods and services available to consumers. (Milbrath, 1979).

The second use of the term quality of life refers specifically to the performance of each of the societal systems. This is essentially the approach taken by OMB in the compilation of the Biennial Social Indicator Report. The performance of each system can be evalutated in relation to its own objective function. For example, the health care system is intended to reduce the incidence and duration of disease processes and to increase the longevity of the population. By comparing life span over time or in different societies or by measuring the changes in the frequency and duration of hospital confinements, it is possible to quantitatively estimate the effectiveness of the health care system. Indeed, in theory, if each of the ten societal systems is analyzed, it should be possible to measure its effectiveness in providing its goods and services across the population. What is required is: 1) to define its objectives in terms of its services; 2) to specify the means by which it is organized to provide goods and services; 3) to evaluate the effectiveness of these means in achieving its objectives. Thus it should be possible to determine for each system the quality of life it provides given its present structure. This performance measure can be defined in absolute or relative terms. For example, the objective of a fire protection system may be stated as prevention of the absolute loss sustained by fires given the state-of-the-art

technology for fire protection and control. The quality of life can also be defined in relative terms: How well a societal system can achieve a specific goal.

If such objective functions can be defined, then a system-specific quality of life metric may be derived: $Q.L._i$. Of the ten quality of life systems, at least five have objective functions that can be so defined. These are food, shelter, clothing, health care and public safety which account for 73% of the total expenditure for personal goods and services. It should be noted, however, that given a $Q.L._i$ function for each of the five societal systems, it does not follow that the individual $Q.L._i$ metrics can be combined to provide a single measure of overall quality of life. Although in the long run this might be desirable, from a transportation standpoint it is sufficient to define a metric for each system.

It does appear possible to develop a performance measure for the major societal systems. It further appears feasible to model the performance of these systems. This, in fact, has been done for at least four of the five systems: food, housing, health care, and public safety. In essence, any of these systems can be analyzed to determine the operations underlying its performance and the criteria for performance effectiveness. As an abstract model, such determination will allow the definition of the maximum or ideal quality of life that each of these systems can provide within the current state of the art.

In the context of this program the reason for conducting these systems analyses is to relate the quality of life output to transpor-

tation, or more generically, accessibility. If accessibility is an important determinant of societal system performance, then allocation of resources to or the design of transportation may be rationalized by its incremental improvement in quality of life. That is, the objective is to define the performance characteristics of accessibility required by a societal system which can satisfy its objective function: the quality of life it can provide. The proposed approach requires a non-modal analysis of the performance requirements for linkage within each societal system. Clearly, these requirements include a wide variety of linkage requirements including capacity, scheduling, routing, ride, handling, command and control. To reiterate, the objective is to define operational linkage models so that all possible technologies for satisfying the demand placed upon systems may be evaluated. This approach is a fairly common one in high technology areas and provides a basis for system concept definition.

This discussion has been concerned with the structure of the societal systems from the providers' standpoint. However, the effectiveness of any of these systems in providing its maximum quality of life is ultimately as dependent upon the consumers of the services as it is on the provider. In almost every societal system, utilization is consumer initiated. In this sense, the societal systems are passive in that they are deployed or ready to be deployed, waiting for the consumer to trigger them into action. Thus, how the consumer perceives or chooses to use the societal system will determine the actual quality of life that any system, in fact, does provide. For example, a citizen

witnessing a crime who is unwilling, unable or does not know how to access the police reduces the effectiveness of the police system. Similarly, an individual who does not know the location of a hospital or how to enter the system will not be able to make effective use of that system. Hence, the quality of health care will be decreased even though the capability exists to treat the individual.

It becomes obvious from this discussion that we may state a general model for the quality of life that any societal system can provide. It may be defined in either of two ways. One is:

$$Q.L._i = (Q.L._i^A - f(D_i, C_j^k C_j^A) \qquad (1)$$

Where $Q.L._i$ = the actual performance of the system

$Q.L._i^A$ = the maximum performance of the system

$D_i$ = delivery efficiency

$C_j^k$ = consumer knowledge of system

$C_j^A$ = consumer access efficiency

The other is a relative model, i.e.:

$$\frac{Q.L._i}{Q.L._i^A} = f(D_i, C_j^k, C_j^A) \qquad (2)$$

That is, the proportion of the absolute quality of life a societal sytem can provide at any point in time is dependent upon its delivery

capability, consumer knowledge of how to use the system and the consumers' capability to access the system. Obviously, the functional form of the model is not determinate at this point other than to say that it is a stochastic one. One of the major tasks in the proposed research program will be to develop the analytic structure. The real concern in this phase of the effort is not modelling the component parts. Rather it is their combination, linear or nonlinear, additive or multiplicative that is the difficult analytic problem. At the least it should be possible to develop the three models independently to produce a method for generating an output in terms of a quality of life measure. It is possible to exemplify the nature of the process that would be the product of this program with a concrete example. This will be done using health care and specifically emergency medical care.

For accidental trauma, cardiac, vascular and certain organ failure, the criterion for survival is the total time delay to between the trauma and the initiation of treatment. The survivor curves are negative exponential distributions of the form:

$$f(t) = re^{-rt} \tag{3}$$

If this function is integrated over some time interval from the time of occurrence of the trauma event, then the proportion surviving can be determined as a function of delay to treatment. Each category of trauma may have a different value for the parameter, r.

If one analyzes the components of delay to initiating life saving treatment, one finds three categories of delay. One is consumer induced delay. A second is a transport induced delay. A third is a supply induced delay. The first is caused by consumers having to find a means of initiating a response from the health care system. The second is the complex of dispatch and travel time delay within the health care system. The third is a delay induced by the unavailability of service within the health care system, e.g. lack of ambulances or lack of staff or facilities for treatment. It turns out that if one analyzes the components of delay to treatment, one finds that in urban areas especially, the dominant delay component in current operations is the travel time of the emergency medical care unit.

Existing data indicates that approximately 25% of the victims of trauma could be saved if treatment were initiated instantaneously. Seventeen percent could be saved if treatment delay were ten minutes or less; 13.1% with a 20 minute delay; and 5% for a delay greater than 40 minutes. At present the average delay to treatment within the health care system is 45±20 minutes. Consequently, one can estimate the relative quality of life for medical emergencies as:

$$\frac{Q.L._i}{Q.L._i^A} = \frac{k\exp{-k}\ (C_d + D_d + HC_R)}{Q.L._i^A}$$

Where

$Q.L._i$ = The proportion of lives saved in the present system

$Q.L._i^A$ = The maximum proportion that could be saved

$C_d$ = Time delay in consumer response

$D_d$ = Transport delay

$HC_R$ = Medical response delay

Since the maximum proportion of lives that can be saved in medical emergencies is 0.25 and since the numerator defines a negative exponential of time, with the current system the proportion of lives that can be saved being 0.06. Hence the relative quality of life provided is 0.24. In this case $C_d$ & $H.C_R$ are negligible compared to the service delivery delay, $D_d$. Clearly, then, the quality of life that the health care system can provide for medical emergencies is constrained by two major variables. One is a transport capability and the other is the geographic distribution of health care facilities. The latter is important simply because the total travel time is in part determined by the distance of the victim from a source of treatment. It should be noted that this whole system may be defined as a single queue multiserver queing model. It can be used not only to optimize the numbers of transport vehicles but also to optimize the deployment of the emergency medical care system in any geographic space. Changes in transport and/or deployment that produce a reduction in treatment delay can be evaluated using such a model to determine the improvement in quality of life for emergency medical care.

This example simply defines societal system effectiveness under the current operation of the health care system and demonstrates the critical importance of accessibility to the quality of life that system can provide. From a transportation planning and policy standpoint as well as a land use planning standpoint, such an analysis provides insight into both the effectiveness of transport performance and insight into the priorities for improving transport supply, operations, and organization.

Another way in which to view the proposed methodology is shown in Figure 1. In the figure, it is assumed that two elements are combined to produce the quality of life. These elements are delivery efficiency ($D_i$) and consumer access efficiency ($C_j^A$). Delivery efficiency in this context means the output of the societal system, e.g., quality and amount of health care for health care systems, or quantity and quality of food for food distribution systems. The further away form the origin, the greater the amount of delivery efficiency provided.

Since the quality of life is related to accessibility to these systems, consumer access efficiency is shown on the abscissa, with greater amounts of access corresponding to greater distances from the origin. The greater the delivey efficiency and consumer access efficiency, the greater the quality of life provided.

The lines labeled $Q.L._1$, $QL_2$ etc. show different levels of quality of life provided by the two inputs to the system. Each line shows alternative combinations of $D_i$ and $C_j^A$ which yield the same level of quality of life. The figure assumes that the same level of quality of life can be obtained through the use of less $D_i$ and more $C_j^A$ or vice

versa. The line labeled $QL^A$ shows the maximum quality of life that can be obtained from the system under current technology.

These iso-quality of life lines are drawn convex to the origin. This shape assumes diminishing returns to increases in one type of efficiency holding the other type of efficiency constant. In addition, the figure assumes that consumer knowledge of the system is constant.

This figure shows how the quality of life can vary across locations as a function of the level of accessibility provided. Suppose the delivery efficiency of a societal system is at the level $D_1$. Two residential locations have different levels of accessibility to the system: $C_1{}^A$ for the first location $C_2{}^A$ for the second. Consumers located at the second location would have a higher quality of life ($QL_2$) than the first ($QL_1$), even though the delivery efficiency of the societal system is the same for both locations.

The effect of current practice in planning societal systems and transportation systems can also be illustrated in the figure. Current practice is to plan the transportation system independent of the societal system. Thus, planners of the societal system can increase the quality of life by increasing the delivery efficiency to $D_2$. The quality of life of consumers at both locations has increased. Alternatively, transportation planners can increase the quality of life by increasing consumer access efficiency at each location, given that delivery efficiency is held at the level of $D_1$. Thus, the quality of life at the first location can be increased to $QL_2$ by increasing its access efficiency to the same level of consumers located at the second location.

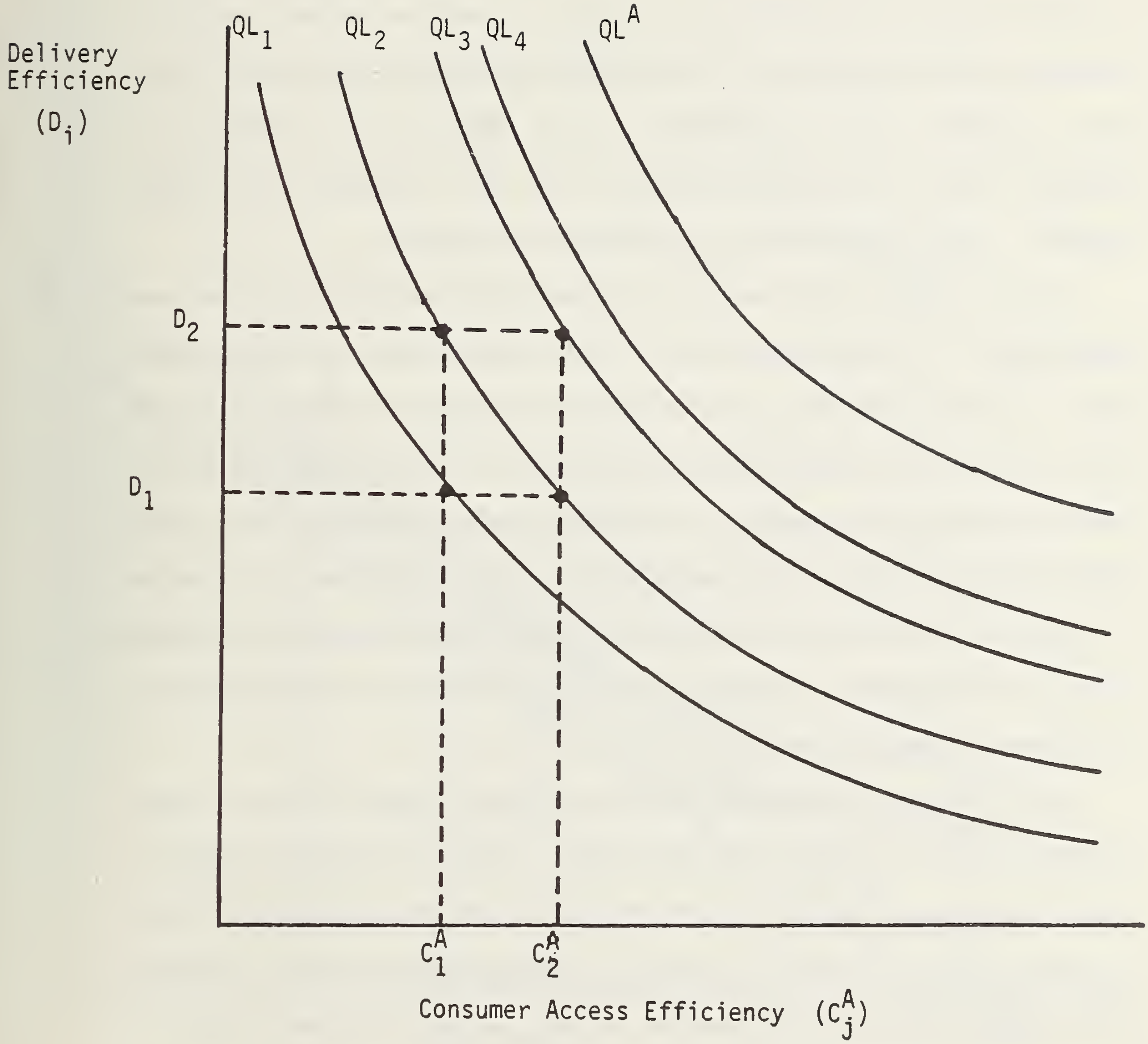



Figure 1: Relation between quality of life, accessibility and delivery efficiency

Current practice, however, is inefficient, in that the same quality of life could be obtained with the use of fewer resources, or alternatively a higher quality of life could be obtained with the use of the same resources. This efficiency can be reduced or eliminated by planning both the societal system and the transportation system together. This proposition is illustrated in Figure 2.

In the figure are shown two lines B-B and $B^1$-$B^1$, which are superimposed on the iso-quality of life lines shown in the previous figure. These lines are iso-cost lines. The slope of each line is the ratio of the cost of providing increments to delivery efficiency to the costs of providing increments in consumer access efficiency. Thus, each line illustrates the costs of increasing delivery efficiency relative to the costs of increasing accessibility. The further the distance from the origin the greater the amount of resources devoted to both delivery and consumer access efficiency.

The situation illustrated in the previous figure for the first location is shown as point I on the figure. The first consumer location could experience a higher quality of life if fewer resources were used to provide delivery efficiency and more resources were used to increase the accessibility of the location to the societal system. Point II illustrates this result. In addition, if both transportation and the societal system were planned together, it is possible to keep quality of life at the same level, and reduce total expenditures to B-B. Point III is an illustrator.

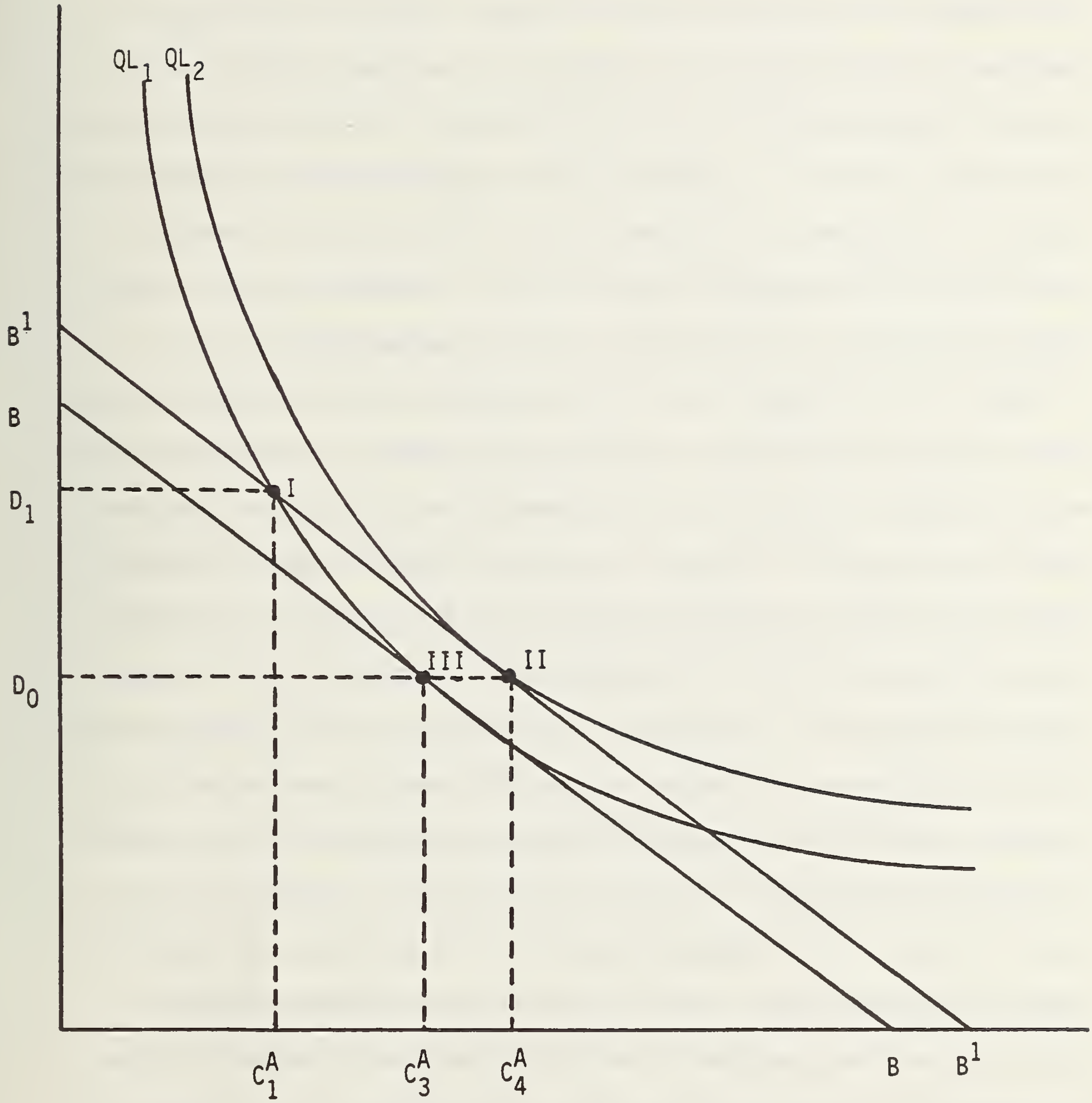



Figure 2 - Quality of life and costs of providing it.

Viewed in this way, the societal systems approach can provide the foundation for a transportation planning methodology. This approach permits a more efficient allocation of resources to both transportation and societal systems. In addition, consumer locations can be ranked on the basis of the quality of life provided. Locations with low quality of life due to access inefficiency can be improved. Thus, a more equitable distribution of transportation services can result.

This discussion has focused on the consumption side of providing goods and services that is, on the output function. In essence, the model structure subsumes the person movement sector as far as transportation is concerned. It should be obvious, however, that a complete model must include the "goods" movement or production side of transportation. To be concrete, the quality of life obtainable by a consumer from the food system is determined by the production and processing of agricultural products and on the mechanics of the distrubution of those products. It is well to note that the quantities produced, in what form and how they are distributed are known in detail. Further, they are known for each of the societal systems. Finally, they are known in terms of regional flows. There is, however, only limited information about detailed intra-regional flows, e.g. urban goods movement. Thus, it is possible to model, starting with the final output of the societal systems, the material flows required by them to provide consumers with goods and services, i.e, a given quality of life. In essence, the question is: How does the production and the distribution process (which includes location) affect the quality of life that the soci-

etal system can provide? The answer to this question is a necessary element in developing the basic measure of system preformance as well as providing the basis for defining the freight (or information) movement requirements for each system.

As was noted at the outset of this proposal, the objective of the effort is to develop an abstract (in the modal sense) model for transportation. The basic focus is on accessibility, both accessibility of materials, information and manpower to providers of societal services and accessibility of the products of these systems to consumers. The modelling activity must be abstract because the quality of life that can be provided depends not only on transportation but also on deployment or location of the provider as well as on general land use considerations. In this sense the approach discussed is essentially a model of social organization. Its aim is to model three linkage elements: 1) the inputs of goods and labor required for an outlet to provide services to consumers; 2) the mechanism by which consumers obtain services; 3) the spatial distribution of outlets for goods and services essential to satifying the performance requirements for delivery of those services.

The research program that is described in the following sections is designed to develop these three models. As was mentioned earlier, there are five societal systems that have definable and quantitative objective functions. Of these we propose to use three for development of the methodology. One is the food system. Second is the health care system. third is the public safety system. The first is selected because it is a private sector system whose operating characteristics including outlet

deployment are determined by classic economic criteria. Health care is selected in part because it is a noneconomic system for which extensive analysis of its operations have already been done. Public safety is selected because it is a public system for which extensive operations analysis has been done, especially spatial organization. In essence, functional models as well as detailed operations analysis have been done for these three societal systems. Consequently they are the most direct ones to use for determination of the relationship between accessibility and system performance and hence for development of a general accessibility model. Further, such a model will allow a better understanding of the relation between spatial organization and transportation. Finally, given such a model it will be possible to examine and evaluate alternative transport strategies relative to the performance of those systems.

Finally, it should be noted that our approach to modelling transportation starts form the consumption function and works back ultimately to the production side. This is the reverse of the historical development of transportation and its planning which has been primarily based on satisfying production system requirements, i.e., freight and labor movements. Although these must ultimately be contained within the structure of the transportation policy and planning process it is our view that these requirements must be derived from the societal sytems. This is simply because production, like transportation, is a service system whose rationalization is its contribution to quality of life.

## Cambridge Systematics, Inc.

Cambridge Systematics proposed to develop a method of examining the location of activities in physical space. The study would outline a general conceptual framework which encompasses all spatial phenomena, and then select a single aspect of this framework for further testing: residential housing and location.

The general framework was characterized by its disaggregate, or micro-behavioral, perspective. All spatial decisions are viewed as made by different actors in a dynamic response to a range of attributes; some of these attributes may be wholly exogenous, and others may be the result of choices of other actors. For example, each household is a distinct actor and makes choices regarding its location and residence. These decisions are influenced by both the decisions of other households (which determine attributes such as neighborhood composition) and decisions of other types of actors such as landlords, retail firms or manufacturers. The framework is also explicitly dynamic in that choices are made over time and can depend on the complete history of prior choices as well as expectations of future ones.

The proposed research was neither highly innovative, nor was it likely to significantly advance our understanding of transportation/societal interactions. The subject area to be investigated in the research -- the residential location/journey-to-work decision -- is already reasonably well understood. The underlying theories on which the methodology was based are currently well established as state of the practice. Moreover, major portions of the proposed model have already been built and tested. The proposed research would do little more than establish a unifying framework for combining these separate model elements. While this approach was obviously low risk, it did not seem to the panel that it would result in any major contribution to the state of the art.

## Interchange (1)

Interchange proposes a research effort which will document and analyze forthcoming demographic changes, their implications for metropolitan residential patterns and growth policy, and in turn the implications for transportation policy. This kind of analysis can provide transportation planners and officials with a clearer understanding of the demographic, housing, and growth-policy context of the transportation investment decisions of the 1980's. Interchange will also prepare a handbook and case study example for use by local planners in their growth projections and analysis.

This research was considered to be valuable and innovative by the evaluation team. The study design report itself provided substantial information of use in ongoing work programs.

Interchange (2)

Interchange proposed the development of a micro-simulation model of an urban area - a model already initially formulated. The model would be used to examine the implications of various theories related to the spatial arrangement of activities within urban areas under a wide range of conditions in the urban economy. The model would simulate the effects of behavior related to the findings of other investigators in a multi-sectoral context. It would not itself be employed to derive theoretical propositions. The model would be operated as a heuristic device, i.e., one by which the accumulated understanding, as well as conjecture about the workings, of the land market and its relationship to transportation can be incorporated in a coherent way.

The approach appeared to be over-simplistic. There was little discussion of the transportation sector, which had several conceptual problems. For example, it addressed only the work trip by head of household, thus ignoring a substantial share of travel that may significantly affect land use patterns. Distance minimization using a single aggregate mode as a motive force for travel choice reduces the influence of policies aimed at cost or travel time. Goods movement and the roles of the transportation sector in the location of industry and in the cost of production were ignored and would greatly reduce the potential understanding of transportation/spatial form linkages.

Problems in the overall model design and in the design of other model sectors also appeared to have been caused by a need to oversimplify to achieve a manageable approach. However, it was not felt that the resulting product would be of sufficient value to justify its development.

The Futures Group

The Futures Group proposed to develop a probabilistic systems dynamics (PSD) model to simulate the interaction of passenger and freight transportation systems with key social and economic factors such as energy availability and cost. The PSD model makes use of the systems dynamics methodology and the development of a set of stochastic exogenous events. In making projections with the model the future values of the endogenous variables depend not only on the system interactions but also on the future events that are included in the model. Thus, PSD is a means of avoiding the assumption that the forces which shaped the system in the past will continue to do so in the future.

The model, which was conceived on a regional scale utilizing aggregate data, was not felt to be a highly useful policy tool. Little advantage was seen in the PSD approach over more conventional dynamic system simulations which are usually used to test best/worst cases.

The proposal, as embodied in the study design report, was not well specified. Only the general process was described, and in a simplistic way. There was little discussion of the relationships that would constitute the model, no discussion of how the various elements would be characterized (including transportation), and no description of how the lack of spatial resolution would affect the value of the model. There was little discussion of data sources or of a time frame for validation or application. Finally, the Futures Group did not appear to have the requisite transportation and economics background and apparently would be relying heavily on TSC for guidance.

Research Triangle Institute

To enable more rigorous quantitative characterization of urban spatial structure and to make practical comparative analysis of spatial structure across cities, Research Triangle Institute will research an alternative method of spatial distribution analysis designed for quantitative treatment of the structure of associations existing between areally distributed urban variables. The approach grows out of a particular combination, and in some instances generalization, of mathematical concepts developed previously within the areas of information theory, urban trip distribution modeling, and the theory of multidimensional scaling. The method will be designed to enable analysis of transportation networks as factors distorting the otherwise two-dimensional travel distances of urban space. The method will also offer the means of quantifying structural associations between urban population, employment, activity, land use and transportation network patterns. These measures of structural association, together with available non-metric multidimensional scaling methods, may yield a new approach for statistical analyses of U.S. urban spatial structures.

The evaluation team considered the approach to be innovative and to have potential for providing a new, valuable framework for urban policy analysis, planning, and research. Although the modelling approach is primarily a descriptive one, it could yield important insights into the nature and implications of urban spatial patterns.

Development Analysis Associates, Inc.

DAA proposed to develop a generic non-linear dynamic feedback simulation model to study the effects of transportation on personal travel, the location of homesites and industries and the patterns of development of urban and surrounding areas. Uses of the model would be oriented toward broad policy analysis and hypothesis testing and empirical validation.

The proposed approach, using the systems dynamics paradigm, was not particularly innovative. Further, it appeared to be overly ambitious; it required defining a comprehensive set of theoretical relationships and operationalizing them in a documented simulation program applied to an entire metropolitan area, incorporating three levels of spatial aggregation. There appeared to be a serious underestimate of the effort required, particularly to define and validate the model equations and to collect, analyze, reduce, and correct the enormous data base which would be required.

The contractor appeared to lack in-house technical expertise in key areas such as economics and transportation analysis. This deficiency contributed to a lack of depth and understanding in the study design regarding key issues and relationships. Thus, it is highly uncertain that the current project design would remain intact during the project life and that it would in fact be successfully completed. The idea of an advisory group, while in principle not a bad one, was an unacceptable solution in this case because of the high reliance on it for conducting the most important portion of the research.

Urban Systems Laboratory (University of Illinois at Chicago Circle)

The Urban Systems Laboratory proposed to develop a methodological approach to modelling the interactions between transport, production and societal systems based on analysis of the linkage requirements of infrastructure service systems. The proposal suggested that transportation policy, planning and design emerge from and must be determined by the societal systems that determine the qualitative goals of the society and their effectiveness in meeting those goals. Transportation, or more generally linkage, is an essential component of the performance of the societal systems. However, the performance of transport is determined by the societal system's requirements, and appropriate allocation of resources to the linkage system( time, money, technology, etc.) is determined wholly by the societal systems they serve. Thus, the ultimate objective was to develop a set of procedures that allow the analysis of these systems in terms of transport and in turn to model the transport characteristics in terms of the societal system's goals and needs.

The proposed research was deemed high risk with a low probability of ultimate success. Although the approach was both innovative and potentially useful in expanding our understanding of transportation/societal interactions, the three quality of life systems (out of the ten discussed) selected for initial investigation appeared to have been the most amenable to, and may have been the only ones which could be addressed by, the proposed methodology.

The discussion of the approach was not well developed and lacked detail in certain critical elements of the work. Specifically, there was little or no discussion of the computational framework within which the models would be developed, the data sources available for model development and testing, or what the final product would be.

It was implied that the product of this research would be useful for policy analysis, but there was no discussion of possible applications. Nor was there any detailed discussion of how the results of the proposed research would significantly advance understanding of transportation and its role in society.

600 copies

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981 500-206/197

Department
ransportation
search and
ecial Programs
ministration
dall Square
bridge, Massachusetts 02142

Postage and Fees Paid
Research and Special
Programs Administration
DOT 513

U.S.MAIL

Official Business
Penalty for Private Use $300